

EVALUATING SUCCESS FACTORS OF HEALTH INFORMATION SYSTEMS

Shahryar Eivazzadeh

Blekinge Institute of Technology
Doctoral Dissertation Series No. 2019:14
Department of Health



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Shahryar Eivazzadeh

Doctoral Dissertation in
Applied Health Technology



Department of Health
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Software credits in the Endnotes chapter.¹

*For Parvin and Asghar,
thank you for everything.*

There was an elephant in a dark room ... ^{II}

—Rumi (1207–1273), *Masnavi*

Only those enjoyed the show

who could see the elephant in its entirety ... ^{III}

—Shams Tabrizi (1185–1248), *Discourse of Shams Tabrizi*

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Acronyms

ACSI

American Customer Satisfaction Index 137, 275

AGFI

adjusted goodness-of-fit index 193, 196

AHRQ

Agency for Healthcare Research and Quality 103

AOE

angular order of the eigenvectors 275

AVE

average variance extracted 148, 150, 151, 154, 278

BPMN

Business Process Model and Notation 223, 269

CB-SEM

covariance-based structural equation modelling 64

CFA

confirmatory factor analysis 196

CFI

comparative fit index 193, 196

COPD

chronic obstructive pulmonary disease 181

CR

composite reliability 148, 150, 151, 154, 278

CSI

Customer Satisfaction Index 68, 135–139, 153, 158, 163, 274, 275

D&M IS

Delone and McLean Information Systems Success 48, 59, 135, 138, 139, 153, 156, 158, 163, 188, 274, 275

DALY

disability-adjusted life year 47, 244, 245

ECSI

European Customer Satisfaction Index 138, 140, 275

EFA

exploratory factor analysis 193

EHR

electronic health record 218, 219

EU

European Union 36, 61, 67, 68, 72, 106, 136, 140, 162, 181, 216, 225, 282

EUCS

End User Computing Satisfaction 158

EUnetHTA

European network for Health Technology Assessment 49

FI

Future Internet 61, 106

FI-GE

Future Internet General Enabler 62

FI-PPP

Future Internet Public-Private Partnership 61, 106

FI-SE

Future Internet Specific Enabler 62

FI-STAR

Future Internet Social and Technological Alignment Research 61, 62, 64–68, 77, 105–108, 113–115, 118, 120, 122, 123, 135, 140, 142, 154–157, 159, 181, 216, 217, 225, 237, 246, 282, 283

FITT

Fit between Individuals, Task and Technology 48, 59, 102

FIWARE

Future Internet WARE 61, 62, 140, 282

FP7

the Seventh Framework Programme for Research and Technological Development 61

GDP

gross domestic product 36, 38

GEP-HI

Good Evaluation Practice in Health Informatics 49, 59

Health-ITUES

Health Information Technology Usability Evaluation Scale 188

HIT

health information technology 187, 188

HITAM

Health Information Technology Acceptance Model 188

HOT-fit

Human, Organization, and Technology Fit 103, 138, 188

HTA

health technology assessment 44, 47, 48

HTMT

heterotrait-monotrait 148, 151, 154, 278

ICCPR

International Covenant on Civil and Political Rights 217

ICD

International Classification of Diseases 241

ICESCR

International Covenant on Economic, Social and Cultural Rights 217

ICT

information and communication technology 44, 189, 191

INAHTA

International Network of Agencies for Health Technology Assessment 41, 42

IT

information technology 44

KMO

Kaiser-Meyer-Olkin 193, 194

LASSO

least absolute shrinkage and selection operator 153

MAST

Model for ASsessment of Telemedicine applications 49, 52, 59, 62, 107, 108, 114, 115, 120, 122, 136, 140, 282

MeSH

Medical Subject Headings 222, 246

MRI

magnetic resonance imaging 239

OECD

Organisation for Economic Co-operation and Development 36, 49

OWL

Web Ontology Language 114

PEOU

perceived ease of use 187, 189

PLS-SEM

partial least squares structural equation modelling 27, 64, 68, 136, 141, 142, 148, 151, 153, 154, 158, 161, 274, 278, 283

PROMs

patient reported outcome measures 47, 72, 263

PSQ

patient satisfaction questionnaire 46

PU

perceived usefulness 187, 189

QALY

quality-adjusted life year 47, 244, 245

RCT

randomized controlled trial 49, 72

REB

research ethics board 231, 239

RMSEA

root mean square error of approximation 193, 196

SEM

structural equation modelling 274

SNAC

Swedish National Study on Aging and Care 28, 61, 62, 64–66, 191, 202

SNAC-B

SNAC Blekinge 191

SNAC-IT

SNAC IT 62, 64

SNOMED-CT

SNOMED Clinical Terms 41

SRMR

standardised root mean square residual 193, 196, 278

STAM

Senior Technology Acceptance Model 188

SUS

System Usability Scale 188

TAM

Technology Acceptance Model 46, 48, 59, 101, 102, 135, 138, 139, 153, 156, 158, 159, 163, 187–189, 274, 275

TAM2

Extended Technology Acceptance Model 46, 48, 102, 275

TTF

Task-Technology Fit 48

UDHR

Universal Declaration of Human Rights 217

UK

United Kingdom 181

UN

United Nations 217

UN-OCHA

United Nations Office for the Coordination of Humanitarian Affairs
303

UTAUT

Unified Theory of Acceptance and Use of Technology 46, 48, 102,
138, 275

UVON

Unified eValuation using ONtology 27, 62, 64, 65, 67, 68, 71, 79, 106,
108, 109, 111, 113–115, 119–123, 135, 136, 140–142, 144, 145, 152, 225,
237, 246, 270, 273–275, 282, 283

WHO

World Health Organization 38, 41, 50

Preface

FOR a long time and as a software engineer by background, I desired to direct my professional efforts towards outputs that make richer contributions to society. My PhD studies in applied health technology was a chance to actualise that desire. I remember, in one of my first readings in my PhD studies, the author —whose name I forgot— had compared the amount of time and talent spent on finding ways for increasing the number of clicks on advertisements, to the more critical issues of society, such as health. His complaint was reassuring to me regarding the decision I made. Now, after finishing my PhD studies, this dissertation summarises the steps I took since then. I hope I can look at it and have the same or even more confidence in the direction I took.

This work is a by-product of collective efforts of a group of people, mainly in the department of health at the Blekinge Institute of Technology (BTH), who try to extend our knowledge on how to recruit technology in the sake of a better health condition for people. My supervisors provided the primary support for creating this work, and here my acknowledgement goes to them: The main supervisor, Dr Peter Anderberg, for his continuous, pragmatic mentorship through the whole process of the PhD study; Prof. Johan S. Berglund, for being a reliable reference of knowledge and vision in the health and health technology; Prof. Tobias Larsson, for his support by trusting in me and providing new perspectives to my works; and, Prof. Markus Fiedler for his wise and generous supervisory.

The study in the health department at BTH has been a delightful experience. My acknowledgement to Ingela Silverflod, the coordinator of the department, from whom, I received the best support through the whole years of study. Thanks to the head of the department, Dr Doris Bohman, who made all the managerial decisions smooth and with consideration. The colleagues at the department, the past and present fellow PhD stu-

dents, and the inhabitants of the north wing of the building made the many hours I spent there enjoyable. So here my thanks go to Ulrika Isaksson and Joakim Frögren as representatives of that community.

My family should be credited with their share in the achievements of my life. Notably, the newest member, my son Arvid, has a considerable share. Since he joined us, he added new meanings, new motivations, new colours, new dimensions and —of course— new challenges to almost everything, including my academic endeavour.

Features of the Manuscript

Electronic (PDF) and printed format of this dissertation, each has a set of features.

1. In order to facilitate reading, there are margin-notes, in italic and starting with a colon, in most sections of the kappa and articles —though, not officially a part of the published articles.
2. There are summary-points sections at the end of each chapter of the kappa.
3. Page numbers in the table of contents, list of figures, list of tables, and list of acronyms are clickable (in the PDF). In PDF viewers, one can enable the table of contents sidebar.
4. For each numerical citation in the text, there is an author-year equivalent entry in the margin, clickable in PDF, leading to the corresponding entry in the reference section. Margin citations are skipped for repeated citations or in marginless sections.
5. There are three indices at the end of the manuscript, indexing the cited authors, titles, and their corresponding journals/conferences. Each entry contains the corresponding page number(s). One might find interesting insights regarding the most cited people, titles, or journals.

Abstract

H EALTH information systems are our technological response to the growing demand for health care. However, their success in their mission can be challenging due to the complexity of evaluating technological interventions in health care. In the series of studies compiled in this dissertation, we looked at the evaluation of these systems. The dissertation is focused on the evaluation of factors that lead to success, where success is indicated by user satisfaction and can be induced by both intervention-specific and individual-specific factors. *:background and summary of all studies*

STUDY I developed a method, called UVON, to elicit and organise the user-demanded qualities in the outcomes of the health information system intervention. Through the application of the UVON method in the FI-STAR project, an EU project which developed and deployed seven e-health applications in seven member countries, ten categories of quality and their subcategories were identified. These qualities formed two questionnaires, specific to the patient and health professional users. Through the questionnaires, the patients and health-professionals users evaluated and graded both the occurrence of those demanded qualities in the project outcomes and their general satisfaction. *:study I and II*

Study II analysed the survey results to find out which of those ten qualities have the highest impact on satisfaction or can predict it better. Two partial least squares structural equation modelling (PLS-SEM) models were constructed, for the patient and health professionals, based on the Unified eValuation using ONtology (UVON) and survey outputs. The models showed that effectiveness is an important quality in creating satisfaction for both user groups. Besides, affordability for the health professionals and efficiency plus safety for the patients were the most influential. A satisfaction index is also introduced for simple and fast inferring of the changes in the outcome qualities.

STUDY V recruited outputs and learnings from studies I and II to design a system that partially automates the process of evaluating success factors in health information systems, making it continuous and real-time, and replacing hard-to-run surveys with automatically captured indicators and analytics. : study V

STUDY III focused on individual-specific factors in using health information systems, particularly the technophilia personality trait. A short six-items instrument, called TechPH, was designed to measure technophilia in users, tuned for older users. The study recruited empirical data from the Swedish National Study on Aging and Care (SNAC) project. Two factors, labelled techAnxiety and techEnthusiasms, are identified by the factor analysis method. A TechPH score was introduced as a scalar measurement of technophilia. :study III

STUDY IV elicited and discussed the ethical challenges of evaluating and researching health information systems. Both a scoping review and a novel systematic postulation approach were recruited to identify twenty ethical challenges. The identified ethical challenges were discussed and mapped into a three-dimensional space of evaluation stages, demanded qualities, and major involving entities (stakeholder and artefacts), which fosters further postulation of ethical challenges. :study IV

Keywords

Health Information Systems, Health Information Technology,
Health Informatics, eHealth, Digital Health, Evaluation, Information
Systems Evaluation, Health Technology Assessment, User Satisfaction,
Technophilia, Evaluation and Research Ethics, System Design,

List of Publications

STUDIES published in journals, included in the dissertation:

1. Shahryar Eivazzadeh, Peter Anderberg, Tobias C. Larsson, Samuel A. Fricker, and Johan S. Berglund. "Evaluating Health Information Systems Using Ontologies". In: *JMIR Medical Informatics* 4.2 (2016). ISSN: 2291-9694. DOI: 10 . 2196 / medinform . 5185. pmid: 27311735
2. Shahryar Eivazzadeh, Johan S. Berglund, Tobias C. Larsson, Markus Fiedler, and Peter Anderberg. "Most Influential Qualities in Creating Satisfaction Among the Users of Health Information Systems: Study in Seven European Union Countries". In: *JMIR Medical Informatics* 6.4 (Nov. 30, 2018). ISSN: 2291-9694. DOI: 10 . 2196 / 11252. pmid: 30504120
3. Peter Anderberg, Shahryar Eivazzadeh, and Johan S. Berglund. "A Novel Instrument for Measuring Older People's Attitudes Toward Technology (TechPH): Development and Validation". In: *Journal of Medical Internet Research* 21.5 (2019). DOI: 10 . 2196 / 13951. pmid: 31124467. (Visited on 06/07/2019)

NON-PUBLISHED studies, included in the dissertation:

1. "Ethical Challenges of Evaluating Health Information Systems"
2. "Design of a Semi-Automated and Continuous Evaluation System: Customized for e-Health Evaluation"

STUDIES published in journals or conferences, not included in the dissertation:

1. Ana Luiza Dallora, Shahryar Eivazzadeh, Emilia Mendes, Johan S. Berglund, and Peter Anderberg. "Machine Learning and Microsimulation Techniques on the Prognosis of Dementia: A Systematic Literature Review". In: *PLOS ONE* 12.6 (June 29, 2017). ISSN: 1932-6203. DOI: 10.1371/journal.pone.0179804. (Visited on 07/03/2017)
2. Ana Luiza Dallora, Shahryar Eivazzadeh, Emilia Mendes, Johan S. Berglund, and Peter Anderberg. "Prognosis of Dementia Employing Machine Learning and Microsimulation Techniques: A Systematic Literature Review". In: *Procedia Computer Science*. International Conference on ENTERprise Information Systems/International Conference on Project MANagement/International Conference on Health and Social Care Information Systems and Technologies, CENTERIS/ProjMAN / HCist 2016 100 (2016). ISSN: 1877-0509. DOI: 10.1016/j.procs.2016.09.185. (Visited on 10/06/2016)
3. Shahryar Eivazzadeh, Peter Anderberg, Johan S. Berglund, and Tobias C. Larsson. "Designing with Priorities and Thresholds for Health Care Heterogeneity: The Approach of Constructing Parametric Ontology". In: *Proceedings of the 20th International Conference on Engineering Design (Iced 15) Vol 2: Design Theory and Research Methodology Design Processes*. 20th International Conference on Engineering Design (ICED, Milan). WOS:000366977500028. Glasgow: Design Soc, 2015. ISBN: 978-1-904670-65-0

PART I

KAPPA

The one who could not be contained in
the six directions of the universe, is now
embraced in a “kappa”...^{IV}

—Rumi (1207–1273),
Divan e Shams

1

Introduction

An unjust ruler asked a saint,
“What is the best way of serving God?”
The saint replied,
“For you, to take midday naps;
so you would not make trouble
for the people awhile”.

— Saadi, *Golestan (the Rose Garden)*, 1258

NOWADAYS, health information technologies and systems are everywhere. They have been in the health care for more than four decades¹ and they still become more prevalent. They reside in the back-ends of health agencies, computers in hospitals, a mobile phone in our pockets, or some unknown place in the cloud. The spending on these technologies and systems is enormous, and it grows fast. However, do these new human-made creatures serve us?

1: Ammenwerth et al. 2004

Does using health information systems make life easier for the patients or health professionals; or it was more comfortable in the old days when they were not around? Are we less vulnerable with these technologies to the risks in health care; or they exposed us to some unprecedented new ones? Can we allocate more money to other essential sections of health care because of the efficiencies these systems create; or they are bottomless wells of spending with little or vague impact? Are the patients more involved in their treatment; or have they been more isolated and deprived of their autonomy? The success of health information systems is dependent on getting positive answers for questions such as the ones mentioned above, while we cannot answer them without evaluating health information systems, in a rigorous scientific and systematic way.

:research motivation

2: Eurostat 2019

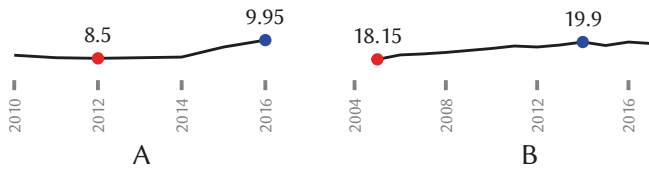


Figure 1.1: Expected healthy years over 65 (A) and life expectancy in absolute value at 65 (B), in EU. Data source: Eurostat.² Visualization: the author.

THE Organisation for Economic Co-operation and Development (OECD) reports on health in Europe 2018³ mentions a variety of statuses and trends that need to be addressed. Almost for each of these challenges, one might think of technological response by using variations of health information technologies. The statues are as follows: Spendings on disability benefits and paid sick leave account for 2% of gross domestic product (GDP), more than the unemployment benefit. Financial inequities, geographic location, and waiting times discriminate against people in access to medical examinations. Lack of appropriate access to primary care leads to unnecessary admissions emergency departments and secondary care. Education discriminates between people in life expectancy. The leading causes of mortality in European Union (EU), cardiovascular, respiratory, and cancer might get alleviated by promoting a healthier life. More than 1.2 death could be avoided if there were better health infrastructures and policies.³

³: OECD et al. 2018

While one might be hopeful of handling the shortcomings mentioned above through the time, but there are also unfolding trends mentioned in the report³ that can counteract our efforts. Life expectancy is increasing, requiring delivery of more service, especially in the older ages. The ratio of pensioners to the working-age population is changing in favour of pensioners. Increasing life expectancy, suggests an inflating ageing population that relies on shrinking working younger generations. The ageing population increases the prevalence of dementia and other cognitive impairments. Health expenditures, 5% to 10% of GDP across EU countries, have been growing. Although Health expenditures share of GDP has not changed, but it is projected that the GDP share of public spending on health care will grow in the future. A higher number of health-professional workforce is needed, while equal distribution is a problem.³

⁴: Eurostat 2019

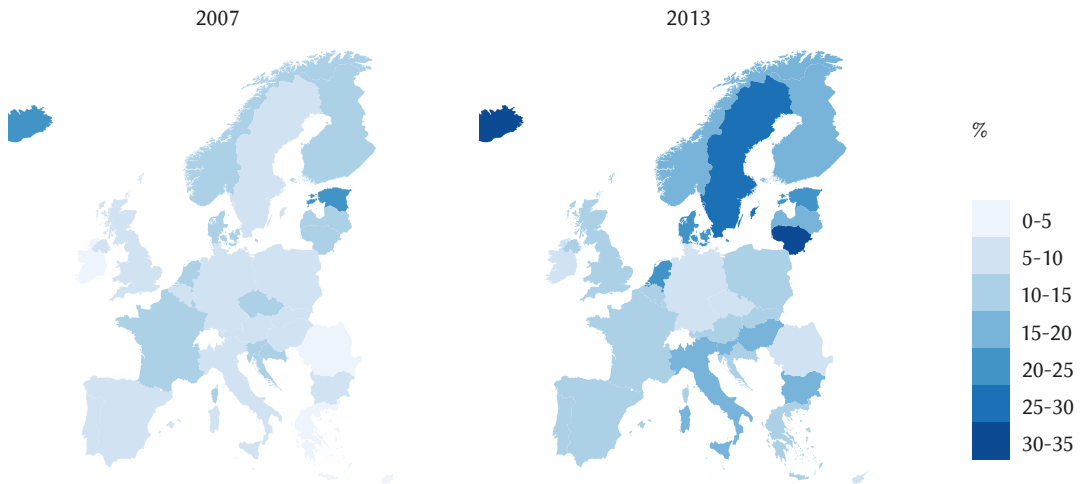


Figure 1.2: The percent of individuals aged 16 to 74 who have done 5 or 6 of the following activities: used a search engine, sent a mail with an attachment, posted messages to chatrooms/newsgroups or online discussion forum, made phone calls, done peer-to-peer file-sharing or created a web page. Data source: Eurostat.⁴ Visualisation: the author.

HEALTH information system, an umbrella wording for other wordings such as e-health, m-health, electronic health records, telemedicine, health informatics, and digital health, is the realization of a set of health information technologies as a system, in the form of device, software application, and networks.

Technologies, especially the information and communication technologies, have been a significant response to various types of burdens in health care. Health information technologies are introduced because they promise lower costs in health procedures by better efficiencies, increased effectiveness, and equal access to health services. Nevertheless, this is a claim that should be proved.

Evaluation of health information systems is not merely proof of these claims, but it constructs the feedback loop that reinforces the right decisions and detects the wrong ones. It is an essential part of learning for better health care in the new age. Human resources, budgets, and opportunity costs allocated to the development and deployment of health information systems only can get optimized if there are relevant and successful evaluations.

FINDING the success factors of health information systems, through evaluating them, usually encounters a plethora of problems. The definitions of health information technology, health information systems, and other terms coined to refer to similar things, such e-health,⁶ are so

5: World Health Organization 2017

In microeconomics, the term refers to the missed value of not choosing an alternative option

:what problems to focus on

6: Eysenbach 2001

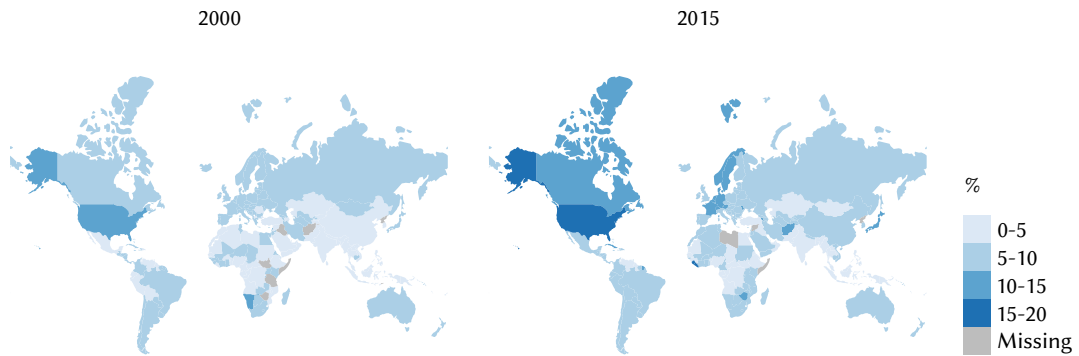


Figure 1.3: Current health expenditure (CHE) as percentage of GDP. Data source: World Health Organization (WHO).⁵ Visualisation: the author.

7: Yusof et al. 2008

broad that a richly diverse set of things are included. This set is highly heterogeneous and usually resists to being evaluated through universally tailored frameworks. From the other side, the success factors of health information systems are not merely dependent on the system itself, but it involves user, setting, and of course task.⁷ Also, the burden and cost of running evaluation can hinder its repetition in a required frequency. This burden and cost should be viewed from this perspective that evaluations are mostly non-automated.

ABOVE discussions bring us to the questions that have been core to the research activities of the author during his doctoral studies. These research questions are as follows:

- Which qualities of treatment, impacted by using health information systems, should be evaluated?
 - How to combine context-specific users' opinion about which qualities to consider for evaluation with experts' general opinion
 - How to overcome the heterogeneity of systems when evaluating them together
- What are the most treatment-level influential qualities in creating satisfaction in the users of health information systems
- What are the ethical challenges in evaluating health information systems
 - What is a possible systematic approach to elicit the challenges

Summary Points

Focus

- Need for research in evaluating success factors of health information systems.

Key Messages

- Trends and status of health and health care demand recruiting health technologies and systems to cope with trends and alleviate problems.
- Evaluation the success factors is an essential part and the feedback loop in making the right decisions and doing the right design for health information systems.
- Evaluating success factors of health information systems can be challenging due to heterogeneity of systems and complex social contexts and settings of applying these systems.

2

Background

DEFINITION of health information technology can be very all encompassing, a consequence of the extensive definitions of health and information technology. WHO defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.”,⁸ which pushes the boundaries of health information technologies even further. It is hard to find out which information systems does not contribute to health, following the above definition. Therefore, it is no surprise that the definition of health technology can also be quite broad. The International Network of Agencies for Health Technology Assessment (INAHTA) glossary defines health technology as:

Any intervention that may be used to promote health, to prevent, diagnose or treat disease or for rehabilitation or long-term care. This includes the pharmaceuticals, devices, procedures, and organizational systems used in health care.

—INAHTA⁹, *Health Technology Assessment Glossary*

Again, such definition embraces a large set of tangible or intangible things, leaving the boundaries of definition blurred. Even if we restrict ourselves to the *useful* interventions, still, there would be quite a lot of heterogeneous items in the list. Examples of the health technology can vary from an ocular prosthesis (artificial eye) implanted in the eyes of a female individual around 5000 years ago to the vast corpus of the SNOMED Clinical Terms (SNOMED-CT) ontology, where one intervenes directly, and the other one establishes a platform for health care improvement.

The vast landscape of *health technology* definition increases the complexity or costs of activities, such as evaluation, that try to take an inclu-

:the vast landscape of health technology

8: World Health Organization 2006

9: Facey et al. 2006

sive, comprehensive, and uniform approach towards the health technology topics. Similarly, the breadth of the definition decreases the efficiency or effectiveness of the evaluation of health technologies by dispersing its focus.

Conquering the vast health technology landscape through dividing into sub-disciplines is a strategy that we already do, but it can also be challenging. Our diverse cognitive sense and historical reasons influence how we categorize health technologies. In the above health technology definition by INAHTA, we can recognize implied divisions by pharmaceuticals, devices, procedures and organizational systems categories, while, the boundaries between these divisions is not very clear. For example, a *procedure* can be a surgical procedure, a procedure within an operation team, or an organizational procedure. The first and the second type of procedures can be grouped into one while we can do the same for the second and third procedures. At the same time, the first and third procedures can be separated far enough from each other to belong to different sub-groups of health technology. This example can be extended to pharmaceuticals and devices subgroups. For example, stomach-resident devices and ingestible electronics¹⁰ are moving toward blurring the difference between devices and pharmaceuticals.

*:the blurred boundaries
between the divisions of health
technology*


10: Zhang et al. 2015

2.1 Health Information Systems

HEALTH information systems belong to two large populations of *information systems* and *health technology*, inheriting the rich diversity of those two populations. Any try to conduct an evaluation over this richly diverse population should take into consideration how the subjects of the evaluation might vary in form, therefore refuting presumptions. As this diversity is inherited from the populations of *information systems* and *health technology*, one needs to look closer at the diversity of items in those two groups.

ONE might think of two dimensions in health information technology. The first dimension is the provision, process, and communication of health-related information. The second dimension is providing or improving health-related services by providing, processing, and communicating the types of information that can help to improve health or the value of health care.⁶ This two-dimensional perspective creates a vast landscape for health information systems, including types of systems

that are not traditionally considered to be in this category.

THE term *information technology* was coined not long time ago. There has been a rise in the frequency of this term since the late 50s and still, it continues (). In Harvard Business Review, November 1958 issue, it is stated that:

:information technology

The new technology does not yet have a single established name. We shall call it information technology. It is composed of several related parts. One includes techniques for processing large amounts of information rapidly, and it is epitomized by the high-speed computer. A second part centres around the application of statistical and mathematical methods to decision-making problems; it is represented by techniques like mathematical programming, and by methodologies like operations research. A third part is in the offing, though its applications have not yet emerged very clearly; it consists of the simulation of higher-order thinking through computer programs.

The Google NGram viewer was used to investigate this through searching the corpus of published texts in English since 1900.

—Leavitt¹¹, *Harvard Business Review*

11: Leavitt et al. 1958

This early definition of information technology departs clearly from the vague but possible definitions that could include even the Sumerian tablets in their defined scope of the information technology. A definition such as the above might be too limited, or might need revisions along with the technological advancements, but it can be more practical than definitions that are too much inclusive. Pragmatism in bounding the scope of information technologies enables us to introduce practical evaluation methods for those technologies; however, it might ignore the fundamental nature of the phenomenon. The balance between pragmatism and comprehensiveness perspectives can be a challenge for the evaluation.

Probably a more transparent account of what we mean by information technology can be addressed by the term *informatics* and respectively *health informatics*. The term *informatics* is coined by Karl Steinbuch in 1957¹² in his book “Informatik: Automatische Informationsverarbeitung”, which translates to “Informatics: Automatic Information Processing” and shows a separation from other forms of information processing by characterizing it as being *automatic*. By this definition—and if we ignore some early analogue computing devices such as abacus and astrolabe which were also very use-case-specific for accounting and astronomy—the new automated computing devices are all those electronic devices, usually based on transistor technology, that automate

:informatics, more to the point

12: Steinbuch 1957

information processing. Though, this perspective lacks the communication dimension, which nowadays we emphasize more by using the term *information and communication technology (ICT)* instead of *information technology (IT)*. However, we can extend our view—but probably not the *informatics* term—when talking about the evaluation of health information technology to include both the automated processing and communication.

2.2 Health Information Technology vs. Health Information Systems

HEALTH information technology inherits heterogeneity and diversity from both health technology and information technology definitions. Though, considering the automation of information processing and the intention to create health or health care outcomes, there is a recognizable zone for the investigations like evaluation.

*:health information systems
and health informatics*

The terms *health information technology* and *health information system* might be used interchangeably in some contexts, but each of these terms has some connotations that we should be clear about them. Evaluation of a specific health information technology instance is usually about evaluating that technology in various applications and cases. This gives a broader perspective of evaluation in contrast to the evaluation of a health information system that is about a definite and enumerated set of health information system implementations. On the other hand, a health information system can recruit more than one health information technologies, where all those heterogeneous technologies have taken part in the whole of that health information system.

The literature of health technology assessment health technology assessment (HTA) emphasizes its role in improving policy makings related to health technology.¹³ It considers lots of economic considerations which implies the *health technology* in HTA is less concerned about specific instances. From the other side, relying more on adoption and acceptance of technology^{14,15} shows the literature on health information system evaluation is more concerned about specific implementations that consist of technologies and human agents combined in the form of a unique socio-technical system. It can be imagined that this separation between domains of concern is not very crisp and clear in all cases or studies; still, a bit of more clarification can explain about the intentions

13: Banta 2009

14: Ammenwerth et al. 2006

15: Holden et al. 2010

of an evaluation or a related study.

THE term *automatic* should not filter out non-automatic agents in the evaluation of health information systems. Health information systems can be composed of automated and non-automated information retrieval, processing and communication agents, including computers and human agents. While we can narrow our focus on cases that include at least one informatics technology, but we cannot ignore the wholeness of the system. The outcomes and qualities we demand from a system are the productions of all subsystems working together.

:the composite nature of health information systems

The holistic and functional perspective on health information systems also implies that a health information system can maintain its core characteristics and functionality, while the underlying technologies can be replaced totally. This is a drastic departure from the health technology and its volatile character. In the holistic and functional view, the technological changes do not change our perspective and approach to the evaluation of health information systems, and the evaluation aspects maintain to live much longer than the life of the underlying technologies.

It looks like a paradox that we sometimes use *health information technology* and *health information system* terms interchangeably; while at the same time, a functional perspective on *health information systems* can make them invariant against technological changes. The same story can be valid between different levels of technology, for example, from the user perspective the mobile communication technology is the desired functionality, and the type of transistor technology being used in the mobile device is not important for most of the users. Here, the functionality survives much longer than its underlying technologies making the evaluation (of system or technology?) to sustain for a longer time.

2.3 Success for Health Information Systems

SUCCESS indicators can be a major output from any evaluation activity. Though, evaluation, even a summative one, does not necessarily need to be normative or specify a success indicator. Through evaluation, one might discover and analyse various outputs and impacts of a system or technology, but presenting the whole outputs through a unidimensional scale is not the same as the former activities. However, most of the time, it is required to have a success indicator. Managers and policymakers need easy to interpret indicators which can be used through the decision-

making process. Any report on the success or failure of a system, tacitly assumes that there are controllable factors that can be controlled to change the faith of a system. A normative success indicator confirms if the past decisions were right or wrong, thus to repeat or reinforce the right ones and avoid or fix the wrong ones. That is what drives the evolution of the health information system.

SATISFACTION is a fundamental component in success-based or acceptance-based models, besides the models that have put it on top of other goals. Measuring satisfaction is usually performed through direct questioning through either one or more question, or by looking at some proxy indicators. The relation between patient satisfaction and the quality of care has been investigated, at least, as early as the 80s.¹⁶ Different studies have explored its meaning,^{17–19} measurement methods, variation of quaternaries,¹⁷ determinants or predictors,²⁰ and various forms of patient satisfaction questionnaire (PSQ) has been developed. This relation has also got specific in the context of health information systems, such as telehealth.

16: Cleary et al. 1988

17: Ware et al. 1983

18: Williams et al. 1998

19: Williams 1994

20: Jackson et al. 2001

ACCEPTANCE, or adoption in other wording, is a very commonly used indicator for the success of a system or technology. The well-established Technology Acceptance Model (TAM) family of models, that is TAM, Extended Technology Acceptance Model (TAM2) and Unified Theory of Acceptance and Use of Technology (UTAUT), have put acceptance at the core of their proposed models.^{21–23}

:acceptance is a widely used indicator of system or technology success

The acceptance indicator for an information system has the possibility of being directly measured using the actual usage of that system. This measuring, of course, should be performed with a caveat against misunderstandings and preferably comparing it with alternative methods. For example, just the time spent on a system might be a defective way for measuring the actual usage, in comparison to measuring the number of successful transactions or performed jobs. The former indicator might represent not the actual work but the potential pitfalls of a poorly designed system.

21: Davis 1985

22: Venkatesh et al. 2000

23: Venkatesh et al. 2003

:acceptance definition is mainly based on voluntary usage, but mandatory usage is also covered in some studies

It should be noted that while acceptance definition is mainly on volunteer usage of a system or the mandatory usage^{24,25} is also covered with some considerations in other studies.²³ The volunteer acceptance is the one that TAM was based on.²¹ It is easy to interpret volunteer usage as a sort of acceptance, but the interpretation of the mandatory usage might

24: Hu et al. 1999

25: Yousafzai et al. 2007

be more tricky. In a mandatory setting, the user who has not accepted the technology might delay, inhibit, hinder, sabotage, and underuse the system or leave the organization.²⁶

26: Markus 1983

WHEN it comes to health information systems, an intuitive measurement of success can be the health outcomes caused by using those systems. Widely used indicators for measuring the outcome of health interventions, such as the rate of mortality, rate of morbidity, quality-adjusted life year (QALY), and disability-adjusted life year (DALY), can also be candidates for measuring the success of health information systems. These indicators can be measured independent of user opinion, which makes them objectives, in contrast to subjective measures such as patient reported outcome measures (PROMs). Actually, in HTA literature, it is common to calculate indicators, such as QALY and DALY in order to compare two health technologies.

:health impact of health
information systems

The challenge with using those indicators is that the type of impact created by a health information system is not necessarily captured by those indicators, at the same time it might be very challenging to capture the impact of health information systems that is relevant to those indicators.

2.4 Evaluation of Health Information Systems and its Frameworks

THERE are many evaluation frameworks for the health information system. These frameworks try to answer why to evaluate, when to evaluate,²⁷ who is involved, what to measure, and how to measure.²⁷ An expert's opinion on definition of health information systems evaluation, reads as: "Evaluation is the act of measuring or exploring properties of a health information system (in planning, development, implementation, or operation), the result of which informs a decision to be made concerning that system in a specific context".¹ An evaluation framework is a guide on performing such action in order to reach the result mentioned above.

27: Wyatt et al. 2003

In addition to being a guideline, evaluation frameworks can also suggest the success criteria for the health information systems, offering a definition for success such as satisfaction, acceptance, or fit. A suggestive framework can be either an extension to other general frameworks or

models like TAM and Delone and McLean Information Systems Success (D&M IS), or specific to the field of health information systems, such as Fit between Individuals, Task and Technology (FITT). Measuring the success of a system can be crucial for the right decisions in investing and policy makings. In many technology assessment studies, including the HTA studies, the main concern is the improvement of effective and efficient decisions, and policy makings.²⁸ The same is true for the evaluation of other types of information systems.²⁹

28: Banta 2003

29: Irani 2002

The success of health information systems can be articulated similar to success in other technological systems, measuring acceptance. Models such TAM, TAM2, UTAUT put the *acceptance* as the cornerstone of success in a technology implementation^{24, 23}, where acceptance can be detailed more as usage when it is voluntary or keep it as the overall user acceptance when then usage is mandatory.^{14,30} TAM and TAM2 put *behavioral intention to use (acceptance)* at the center and then expand it *perceived usefulness* and *perceived ease of use* determinants.^{15,31} Almost similar to TAM and TAM2, UTAUT considers *performance expectancy*, *effort expectancy*, *social influence*, and *facilitating conditions* as the determinants of acceptance. The Task-Technology Fit (TTF) puts the fit between the task and technology as the major indicator of success.³⁰ The FITT model puts the interaction between the user and task in the TAM and TTF combination by creating a triangle of *fitting* relations between task, technology, and individual.¹⁴

30: Goodhue et al. 1995

31: Davis 1989

However, while acceptance studies focus more on *usefulness* by measuring acceptance of a particular technology or system,¹⁵ there is more for health information systems. Health information systems reside in a health setting and clinical effectiveness —if possible to measure— are important indicators. Even besides the clinical effectiveness, the scope of evaluation in health information systems can be extended to include other aspects, such as diffusion, transfer, or social impacts of the system or technology.¹³

32: Cheng et al. 2007

Evaluations can be more case-specific by taking a bottom-up approach and eliciting the required qualities from the stakeholders of the case system. Requirement engineering is the practice that takes this approach.³²

:failure of evaluation

EVALUATION of health information systems is a challenging endeavor and prone to failure.^{33–35} A systematic review in 2006, while confirms the positive impact of health information technology in some aspects, but warns about inconclusive results in others. Some of those challenges

33: Littlejohns et al. 2003

34: Kreps et al. 2007

35: Greenhalgh et al. 2010

which caused inconclusive results are inefficiency in time utilization, insufficiency in cost data, limited availability of evidence in specific aspects, and the inability to generalize the study results.³⁶ We discuss some of these challenges here. Furthermore, we considered some of those models and frameworks that try to frame the technology evaluation and its challenges.

36: Chaudhry et al. 2006

THE challenge of diversity in the evaluation aspects of health information systems is usually addressed by suggesting a universal and static list of evaluation aspects. Many of the previous works,¹ or recent generic frameworks such as European network for Health Technology Assessment (EUnetHTA): *HTA Core Model*,³⁷ OECD: *Health Care Quality Indicators Project Conceptual Framework*,³⁸ or recent field-specific models such as Model for Assessment of Telemedicine applications (MAST)³⁹ and Good Evaluation Practice in Health Informatics (GEP-HI)⁴⁰ are examples of trying to address *what to evaluate*⁴¹ part of the evaluation by suggesting universal static list of evaluation aspects.

:static evaluation frameworks and their challenges in keeping relevant

37: Lampe et al. 2009

38: Kelley et al. 2006

39: Kidholm et al. 2012

40: Nykänen et al. 2011

41: Yusof et al. 2008

While the responses mentioned above provide unified frameworks for evaluating different health technology cases in a universal form, but they are static frameworks with no mechanism for accommodating unforeseen, time-variant, or context-specific evaluation aspects. Being static and unable to accommodate new aspects, and at the same time trying to be universal, in contrast to being case-specific, can weaken the relevance relation between those frameworks and a case, hence making it challenging to apply the framework.

THE episode of intervention propagation is a major determinant for fixing other variables, such as the temporal scope (when to evaluate) or the spatial scope (the impact on who or on what should be evaluated).

:the challenge of choosing the episode

Clinical (or epidemiological) episodes can be of decisive importance for impact evaluation of any health care intervention. The evaluation of clinical episodes is usually dominated by clinical trial methodology;⁴² but for the health information system it is subjected to some challenges and limitations, such as those in the application of randomized controlled trial (RCT) or identifying objective parameters to evaluate.^{43,44} From the other end, evaluation of a health information system just as a standalone system, i.e. at the very early episode of impact propagation journey, can barely be considered a matter of health information technology topics. An isolated or technical evaluation of health information system

42: Williams et al. 2003

43: Shcherbatykh et al. 2008

44: Bürkle et al. 2001

is probably a matter of concern for other technology disciplines, such as software engineering. Between these initial and ending episodes of impact propagation, there exists one or more episodes where the health information system can be evaluated by its impact on the surrounding health setting, processes, or knowledge. As defined by WHO the health setting is “the place or social context in which people engage in daily activities in which environmental, organizational, and personal factors interact to affect health and wellbeing”.⁴⁵ This definition can be detailed or be extended by taking into consideration the processes and embodiments of knowledge within that space or context beyond just the entities. Many evaluation frameworks focus on addressing the evaluation of this range of impact propagation episodes and their corresponding health settings.

45: World Health Organization 1998

EVALUATION aspects, i.e. the answers to *what to evaluate* in an intervention, can be constrained by specifying some of the contextual factors. Which episode in the course of the impact propagation is considered? Which actors are in that episode? What time-span of observation is chosen. The answers to these questions shape the list of evaluation aspects that should be considered. Evaluation aspects can be both extracted from internally defined requirement documents of a system or be adapted from a universal external evaluation framework. Here the requirements are those quality attributes (non-functional) that are expected from the system by its stakeholders and determine the overall qualities of the system.⁴⁶ In a different approach, a universal external evaluation framework, by probably sampling similar systems, determines universally what quality attributes are supposed to be required for that type of system. In any of the indigenous or exogenous origins of evaluation aspects, for an overall evaluation of the system, it is needed to find an aggregation and integration method for individual actors’ responses in each specified aspect. The aggregation and integration add to the problem of *what to evaluate*. Successful implementation of these two approaches needs to solve problems with the diversity of actors, heterogeneity of their responses, and the relevance of each evaluation aspect for each actor.

:evaluation aspects, internal or external

46: Dobson et al. 2007

2.5 *Spatial Scope of Evaluation*

SPATIAL scoping comes after determining the intended propagation episode. Different spatial or temporal scales in the evaluation of a health

:the challenge of the right spatial scoping

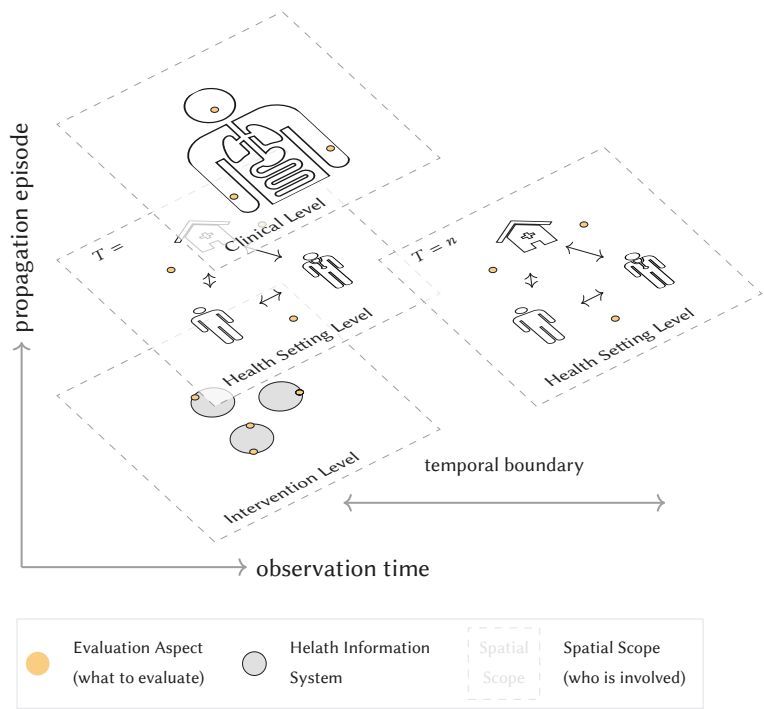


Figure 2.1: Health information system intervention propagation

information system can result in different outputs. The spatial and temporal dimensions are not necessarily dependent, hence fixing the scale in one might determine, or limit, the scale in the other one. Fixing the spatial scope, i.e. determining the actors engaged in that episode, lets us consider a stable situation based on the impact response of those actors. Reaching the stable situation, if there exists any, determines the minimum time we should wait to be able to evaluate. In some cases, observing beyond this minimum time might change our insight about who is involved in that episode, hence changing the spatial scopes in the other way.

In the spatial dimension, references to evaluation aspects indicate, explicitly or implicitly, the context, the environment, or the actors in the space for which the evaluation should be or can be performed. For example, the organizational aspect mentioned in MAST framework³⁹ suggests the organization scope and its relevant members as the scope of the evaluation.

NEGLIGENCE about the networked nature of many health information systems can be a cognitive fallacy in determining the right spatial scope of the evaluation of health information system. Many of the health information technologies address a group of people together, but not separated individuals.⁴⁷ Health information systems are examples of such socio-technical networks,⁴⁸ where the health care value is created, delivered and consumed in a network of different technologies and different stakeholders.

:network blindness cognitive fallacy

47: Lilford et al. 2009

48: Winter et al. 2011

2.6 Health Information Ecosystems

:the four zones of health information ecosystems

To better understand the ecosystemic nature of health information systems and their working context, let us consider a model that specifies classes of actors, their contexts, and their interactions as it is expressed metaphorically in Figure 2.2.

In this model, an ecosystem is formed around a set of health information systems that are targets of evaluation. The health information systems and the digital environment where they reside, and probably interact with each other, is called the *digital actors zone* (the *D zone*). The community of other digital software or hardware entities, more likely working as infrastructures serving digital information and communication technology services to the digital actors and also the user actors,

is recognized as another zone, called *digital infrastructure* zone or simply the *infrastructure* zone (the *I* zone). The infrastructure zone has more blurred boundaries due to its definition. The users' community and their interaction with each other, related to those health information systems, is called *user actors* zone (the *U* zone). The social and physical environment that hosts these users is recognized as *socio-physical* zone (the *S* zone). This zone also lacks crisp boundaries due to its definition.

The model emphasises that each of these four zones is neighbouring the other three ones. These adjacencies create six connection points between the zones. Each of these six connection points represents the flow of value, information, or other exchangeable objects between the two zones. We can consider that each connection point is made of two unidirectional channels, each lets the flow of value, information, and so forth in the opposite direction of the other. In this sense, we have twelve connection channels, through which a zone, or one or more of its members, receives values or information from another zone, or one or more of its members. Each of these channels can be shown by a notation like $X \longrightarrow Y$, where X and Y can be any of D , U , I , S zone symbols.

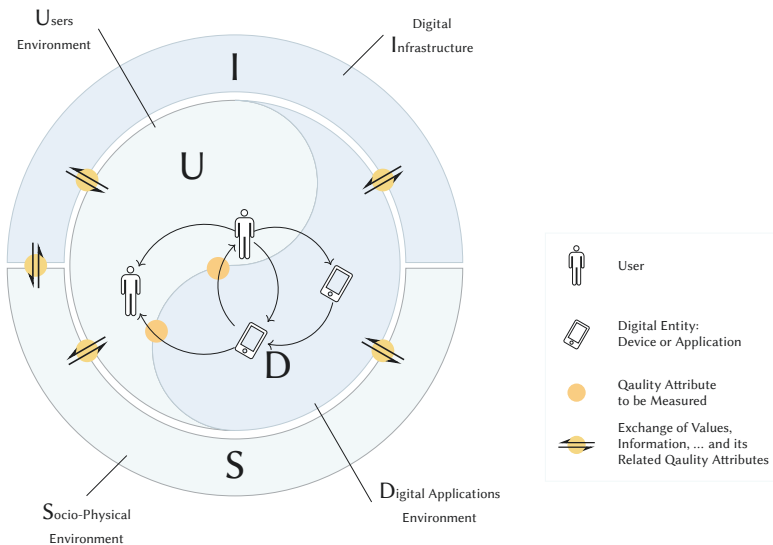


Figure 2.2: SUID Model for Health Information Ecosystems

2.7 Semantic Scopes

HEALTH information systems inherit this diversity from health information technology definition. The widespread presence of information concept in different forms of health technologies is the connecting line that suggests this inheritance. While traditionally, the term *health information system* refers to software systems that are implemented in digital electronic devices, but in the context of evaluation, separation of this kind of information technology from other *information* related technologies is not justified. Health care information systems, the information systems that are specific to health, refer to “socio-technical subsystem of an institution, which comprises all information processing as well as the associated human or technical actors in their respective information processing roles”,⁴⁸ with the speciality in health. This definition can also be extended to encompass both larger and smaller scopes instead of an institution. The extents of health information system definition can be blurred as in a more relaxed view, a stethoscope is a device that senses signals and represents the amplified information in audio format; written instructions or procedures are software applications running on human hardware; and even pill is a chemically encoded information package to be received by cells.

:the broad definition of health information system

2.8 Temporal Scope of Evaluation

TEMPORAL boundaries can be quite challenging for an evaluation framework to suggest. When an evaluation framework has positioned itself at the clinical level, then it can follow up on the rules and traditions in medical science for determining the temporal scale, i.e. to determine *when* is the right time for performing the evaluation. However, when the evaluation framework is positioned in between the intervention and the clinical stage, i.e. evaluating the impact on health setting in our case, then there is usually a list of heterogeneous evaluation items that do not necessarily share the same response time to the intervention.

:temporal boundaries challenges

We should also pay attention to two types of interventions, the one that wants to return the situation to a predefined baseline situation and the one that wants to improve the current situation beyond the previous history. In this sense, evaluations at the clinical level can usually be categorized in the first group where it is assumed that there is a normal, albeit adjusted, healthy situation for an individual (or a population),

and the intervention should revert the physiological or psychological situation to that state. However, the impact on health settings might be of both improving or reverting nature. Evaluation time scope for the reverting case is related to the baseline situation, the probability of fully reverting, and the speed of reverting. On the other hand, the evaluation of improvement is related to the stability of changes and impacts.

Things get more complicated if we assume there is no permanent impact; hence, each impact is subjected to some attrition or deformation rate. Even more, the goals that the impacts are supposed to fulfil can erode along the time.⁴⁹ It is not a guaranteed grace to find a period through the life course of a heterogeneous health setting, including the understudy health information system, where all the impacts have reached their state of maturity and stability, while none has reached attrition.

Another challenge with suggesting a temporal framework for evaluation is the context of evaluation itself. The evaluations that are part of policymaking, project assessment, investment performance evaluation, or other time-bounded activities should comply with practical considerations of the whole activity rather than just focusing on the best time for evaluation. The real value of a long-term evaluation can be debated if it is anticipated that new interventions, of totally new characteristics, might replace the current one. In this regard, health technology assessment literature has not much incorporated the dynamic nature of technology in the assessment.⁴⁹

:context and technology
imposed temporal scopes

49: Douma et al. 2007

2.9 Evaluation of Emergent Systems

HOLISTIC evaluation of health information systems is not guaranteed, even if one succeeds in identifying all the involving actors and creating a unified set from their *exposed* evaluation aspects. Unintended and unforeseen impacts might be caused, amplified, or ignited by the health information system intervention.⁵⁰ Some of these impacts are caused directly by health information systems, but as they are not intended and are sporadically reported, they have a challenging path to reach the set of documented evaluation aspects.

:emergent aspects

50: Harrison et al. 2007

In the presence of insight about the networked and complex nature of health care socio-technical environment,⁵¹ beside both the intended and unintended direct impacts, the *emergence* type of impacts that are not associated directly with individual health information system are also

51: Shiell et al. 2008

matters of concern. Emergence behaviours are those behaviours, usually unintended, that appear in a complex system as a result of individual members' activity and interactions, whereas those behaviours are not the properties of any of those individuals separately and cannot be evaluated by observing at the scope of an individual.⁵² The intervention of a health information system within a complex health setting, let us say ecosystem, can contribute to the formation of some emergent behaviours and emergent impacts.

52: Halley et al. 2008

NEGLIGENCE or blindness about an unintended or emergent impact would limit the effectiveness of an evaluation framework, but a more important question is whether those would also invalidate the evaluations or not. Frameworks that have a positivist approach and focus on scientifically measurable indicators are more prone to miss the overall observations about a health information system intervention,⁵³ including the emergent impacts. Some of these overall observations might contradict the more detailed indicators. For example, any positive evaluation based on the decrease in *emergency department length of stay* can be faded if there would be an increase in *patient's estimate of the total length of stay*.⁵³ The first indicator is an objective and measurable aspect, whereas the second one is more of a subjective and emergent nature. An imaginary health information system that improves the first one might worsen the second one. While it might be unjustified to expect that an evaluation framework enlists unpredicted evaluation aspects, but it is reasonable to expect that an evaluation framework is dynamic enough to accommodate new or case-specific insights about more holistic evaluation aspects or resolutions about conflicting ones.

:conflicting aspects

53: Parker et al. 2014

2.10 *Intended and Unintended Impacts*

WHEN evaluating the impact of health information system on a health setting, any reference to the impact of an intervention on those health settings should be insightful about the extents of impact definition.

:intended and unintended impacts

Impacts of an intervention, in a counterfactual manner, are recognized by differences between the condition of presence and absence of the intervention.⁵⁴ In this sense, evaluating the impact of an intervention also encompasses those effects that are side-effects, unintended or are part of the intervention structure and embodiment. For example, the learning curve of a new health information system and the time allocation

54: Ferraro 2009

needed to address that is an unintended impact, which is usually tried to be minimized as much as possible. Sometimes it can be tricky to recognize if a quality refers to an intended value or an unintended effect. For example, a health information system might *increase efficiency* in a health setting by reducing the number of tasks; hence, the *efficiency* is the intended impact of that health information system. However, at the same time, another health information system, such as a medical image processing application, can also be *efficient*, in that sense that it does not take too much time for creating its intended results. In the first case, the health information system contributes to the total efficiency as it is intended, whereas in the second case, it avoids contributing to inefficiencies by being efficient itself. Here in the second case, efficiency is a none-primary or unintended impact. With this insight, evaluating the impacts of a health information system, in episodes before the clinical episode, involves evaluating the main intended impacts, side effects, or by-products of the intervention.

Summary Points

Focus

- Borders of health information systems definition and its implication on evaluating those systems
- What is the definition of success for health information systems
- What are the factors that influence the success of health information systems?
- Evaluation frameworks for health information systems
- Ethics of evaluation of health information systems

Key Messages

- Health information systems can be very diverse regarding that health information technology and information systems are very diverse.
- It is hard to draw a crisp boundary for health information systems. Many information systems can be utilized to im-

prove health; therefore they are health information system in that specific setting and context.

- There is a difference between system and technology, hence in between health information systems and health information technology. A system is an integration of different technologies for a specific purpose, in a specific setting. A technology has numerous instances in different settings.
- Evaluation of a system is the evaluation of the integration of technologies in a specific setting.
- Evaluation of technologies should consider and average all implementation of those technologies.
- Success of health information systems, as a category of information systems, can be measured by the frameworks that measure the success of information systems.
- Health information systems, like any other health intervention, are supposed to create impacts on the health status of individuals and populations. Dimensions of these impacts can be considered the success of those systems. Still, it can be very hard to sense or measure that impact.
- User satisfaction is another success indicator, where the user indirectly reports how he or she was satisfied both with the system per se and probably the actual impact.
- Acceptance of a system is a success indicator, which can be categorized as volunteer and non-volunteer. Acceptance of a system is virtually independent of the actual impacts, but one might assume that there is a reverse correlation with a low impact system and its acceptance.
- Success indicators might be explicit, such as user satisfaction expressed in surveys, or tacit, arguably such as the rate of using a system in comparison to other systems or methods.
- There are two categories of factors that influence the success of a health information system: pre-intervention: which are only specific to users, and post-intervention: which are related to the system, users, and the context of usage

- Pre-intervention factors are mostly considered as pairs of technophobia vs technophilia or techno-anxiety vs techno-enthusiasms.
- Some evaluation frameworks that are specific to health information systems, while some are more generic about technology or information systems.
- Evaluation frameworks can suggest aspects or qualities be evaluated. These suggestions are usually universal and non-context-specific.
- Among the generic evaluation models one can mention the TAM family and D&M IS model, where both have been utilized in the health information systems context.
- Among the field-specific evaluation frameworks one can mention FITT, MAST, GEP-HI.
- Evaluation process can have an impact on the subject of evaluation, therefore evaluating health information systems might rise to similar ethical challenges as other health interventions.

3

Methods and Materials

FIVE studies are included in this manuscript, and they have interrelations and dependencies, both in methods and materials. Studies I and II share the same empirical materials from the Future Internet Social and Technological Alignment Research (FI-STAR) project, where study II uses results from the study I also. Study III recruits results from the Swedish National Study on Aging and Care (SNAC) project. Study IV relies on some outcomes from study I. Study V embeds methods from the studies I and II.

3.1 *Research Context and Materials*

THE FI-STAR project, an EU project in the the Seventh Framework Programme for Research and Technological Development (FP7) programme,⁵⁵ was the source of empirical data for the studies I, II, and IV; a test bed for study I; and at the same time a stimulator for study III. The FI-STAR project is defined in the Future Internet Public-Private Partnership (FI-PPP) programme of the the Seventh Framework Programme for Research and Technological Development . FI-STAR consists of seven e-health cloud applications that were developed and deployed in seven EU countries. The project relates to the Future Internet (FI) series of technological platforms, and each application was supposed to utilize the FI platform to some extent. Each of the applications serves a different community of patients and health professionals.⁵⁶ The FI-STAR project did not impose any constraint on the type of applications being developed, but they were required to follow the general requirements of the FI-STAR project, especially using the Future Internet WARE (FIWARE) infrastructure. A summary of all subprojects can be found

:the FI-STAR project

⁵⁵: Publications Office of the European Union 2016

⁵⁶: FI-STAR Consortium 2014

in Section 9.A.

The main intention of the FI-STAR project was to run a feasibility study of using the FIWARE platform, utilizing its Future Internet General Enabler (FI-GE) and Future Internet Specific Enabler (FI-SE) features. It is believed that a widespread FIWARE platform can foster the development of a new generation of internet services, including but not limited to health care services. Moreover, a *software to data* approach can be implemented using FIWARE platform, which can be very instrumental for health care solutions. In this approach, health care applications migrate to the data centres which store health care information. This model is in contrast to the conventional model where data needs to be transferred to cloud servers in order to get processed. The *software to data* model can resolve many of the challenges of implementing health data privacy rules and regulations.⁵⁷

:the purpose of the FI-STAR project

57: Sotiriadis et al. 2013

The evaluation instrument for the FI-STAR project, that is the two questionnaires in Appendices A and B, was created using the proposed Unified eValuation using ONtology (UVON) method in the study I.⁵⁸ Both the qualities that were expressed and required by the users in the FI-STAR requirement document and the evaluation aspects specified in the MAST evaluation framework³⁹ were fed into the UVON method. The heterogeneity of evaluation aspects through the e-health applications of the FI-STAR project required an approach to reach a unified perspective for evaluation that led to the UVON method. It was also required that the UVON method could expand and include new cases, merging in some new evaluation aspects from a new case or suggested by another evaluation framework.



Recruitment of the survey participants was performed through the convenience sampling method. The patient and health professional users at each e-health application deployment site were asked to assess the impact of using their specific application on the qualities of treatment or health setting. No precondition was specified for participation, and it was voluntarily. There were almost two months between deployment of the applications and filling in the questionnaires. Users had the option to choose between online or paper questionnaires. 87 patients and 31 health professionals filled in the questionnaires anonymously. Evaluation report, as a part of the work package 6 of the FI-STAR project, was drafted based on the results of the questionnaires.

:UVON was created based on the FI-STAR requirements

58: Eivazzadeh et al. 2016

STUDY III is based data from a part of SNAC project, called SNAC IT



Figure 3.1: FI-STAR trial sites. **Tromsø** → diabetes tele-medicine, **Leeds** → back tracking pharmaceutical products, **Krakow** → cancer patients management , **Munich I** → operation room consumables tracking, **Munich II** → facilitating transportation for patients with mobility problem, **Bucharest** → rehabilitation monitoring for patients with hear failure problem, **Bologna** → information sharing for patients with COPD, **Bilbao** → interactive system for communication between patients with mental health problem and health professionals.

(SNAC-IT). SNAC is a long-term study project focusing on ageing and its associated health care situation in Sweden. The project started in 2001 for four areas in Sweden, please refer to Figure 3.2. SNAC-IT is a part of the whole project that focuses on the interaction of the ageing people and digital tools and content, and how interaction can be enhanced.

3.2 *Methods*

FOR study I, a literature review was performed to find the answer to this question: how we can elicit required qualities from a heterogeneous set of systems and integrate them into a hierarchy or network of connected concepts. The answer was a set of methods of creating ontologies for domains of knowledge. The UVON method is a customised version of those methods which creates an ontology, with required specifications, for the qualities associated with a heterogeneous set of systems.

Validation of the UVON method was performed in two steps. In the first step, reflected in study I, the case leaders of each e-health application in the FI-STAR project were asked to validate the relevance of the created questionnaires to their case. Also, the users, patients or health professionals, implicitly validated the questionnaire by filling in the questionnaires without showing rejection or replying random answers. The second step of validation was performed in study II, where the influence of each elicited qualities by the UVON method was examined against satisfaction in each of the patient and health professional groups. The partial least squares structural equation modelling (PLS-SEM) models in study II showed that the selected qualities by the UVON method could explain the variations in satisfaction relatively good, that is $R^2 = 0.44$ for the patient and $R^2 = 0.89$ for the health professional models. Furthermore, the reliability and discriminant validity tests showed that the UVON method was successful in finding and correctly assigning sub-questions for each quality.

IN study II an exploratory step was taken by using correlation matrices and observing the possible grouping of the subgroups of qualities. In the next step, PLS-SEM models were constructed, building on the results from study I, using categories of qualities as constructs and their corresponding subcategories as manifest variables. Based on the coefficients in the PLS-SEM models, a satisfaction index was introduced.

PLS-SEM model has some advantage over covariance-based structural



Figure 3.2: SNAC sites.

:methods of study I

*:validation of the UVON
method*

:methods of study II

equation modelling (CB-SEM) model, including its lower requirement on sample size and being able to cover non-normal data.⁵⁹ It is also suitable for investigating the structure of relations between constructs,⁵⁹ which was our purpose in study II to find the relation between the qualities and satisfaction constructs.

59: Hair et al. 2011

STUDY III relies on data from the SNAC project. It applies factor analysis, both in its exploratory and confirmatory modes. At first, a survey on questionnaire instruments that measure technophilia led to suggesting a new six-item instrument, which is supposed to measure technological enthusiasm and technological anxiety among older people, from the SNAC project population. The results of the survey were analysed first in exploratory factor analysis, suggesting two latent factors. Then a confirmatory factor analysis was performed by dividing the questionnaire into two factors, enthusiasm and anxiety, each consisting of three items. The result was validated and discussed.

:methods of study III

STUDY IV performs a scoping review, constrained by the search string specified in Sections 11.A, 11.B and 11.C. The results are mapped into a three-dimensional space, consisting of *evaluation stages*, *active entities*, and *demanded qualities* dimensions. The study recruits the results of applying the UVON method in the FI-STAR project to populate the demanded qualities dimension. Further ethical challenges were postulated by looking through the three-dimensional space and considering situations where one of the qualities are impeded or undermined.

:methods of study IV

STUDY V pursues design research methodology.^{60,61} In this regard, the design of a system that can perform semi-automated and continuous evaluation was investigated in the steps of identifying the problem, expressing the objectives of the solution, designing and developing components, demonstrating the results so far, and evaluating. Parts of demonstration and validation are already performed in the studies I and II.

:methods of study V

60: Blessing et al. 2009

61: Peffers et al. 2007

3.3 Ethical Considerations

IN both the FI-STAR and SNAC projects, the ethical assessment was performed, while it was not on the agenda of the author. For the FI-STAR project, it is documented in the project's deliverable D6.4.⁶² For the SNAC project, one can refer to its published studies.⁶³

62: Niezen et al. 2015

63: Lagergren et al. 2004

Summary Points

Focus

- the FI-STAR project
- The SNAC project

Key Messages

- The UVON method from study I was used in the FI-STAR project to elicit user-demanded qualities.
- Results of the evaluation instrument, two questionnaires, produced by applying the UVON method in FI-STAR was used in the study II to create the PLS-SEM models. The models helped to find out which of the qualities contributes more to create satisfaction.
- Scoping review and the qualities from study I populated a three-dimensional space in IV to elicit and postulate the ethical challenges of evaluating health information systems.
- Through design research method, a design is proposed in study V for semi-automated and continuous evaluation of health information systems. Results and methods from I and II were reused.
- By reviewing the literature, a short instrument was introduced in study III. The study applies exploratory and confirmatory factor analysis.

4

Summary of Studies

FIVE studies are included in this dissertation, drawing a connected line that begins from study I, finding what to evaluate and suggesting how to evaluate. Then these whats and hows get realised in the context of an EU project in study II, giving insights about which qualities should be taken into consideration for reaching success, that is the user satisfaction. Study III extends backwards by giving insight about pre-implementation success factors, specifically focusing on technophilia in users. Study IV rectifies the whole line by alerting on possible ethical challenges in evaluating health information systems. Study V transcend the whole package to a semi-automated, continuous, and real-time solution. *:summary of the studies*

STUDY I develops a method, called UVON, to find out which qualities in health setting and treatment should be considered for evaluation. For this purpose, the method integrates and organises the qualities that users expect as the result of using the subject system, by creating an ontology. The UVON method is applicable in similar situations, not limited to health information systems, where a heterogeneous set of systems should be evaluated for their impacts. The UVON method was applied in the FI-STAR project, which resulted in an ontology from which two questionnaires were elicited. The questionnaires, for both patients and health professionals, inquire about the impact of the developed and deployed health information systems in the project, in term of the changing qualities.

The patient questionnaire was filled in by 87 patients, where 31 health professionals filled in their related questionnaire. In both questionnaires, almost the same set of qualities were asked. However, minor modifications were applied to make each questionnaire more relevant to its

target group. In this sense, the questionnaire for the health professionals asked more details and addressed two more qualities. Through both questionnaires, the respondents specified the extent to which the mentioned qualities have been improved in the health setting or treatment process, by using the e-health application. The result of the survey also was published in the D6.4 deliverable of the FI-STAR project.⁶⁴

64: FI-STAR Consortium
2015

STUDY II analyses the survey result from study I to find out which qualities have the highest impact on satisfaction, or can predict it better. Two PLS-SEM models were constructed, for the patient and health professionals, based on the UVON and survey outputs. The models suggest the relationship between the impacted qualities by the health information systems from one side, and the satisfaction of users, patient and health professionals, from the other side. The models show that effectiveness is an important quality in creating satisfaction for both user groups. Besides, affordability for the health professionals and efficiency plus safety for the patients are the most influential.

Because of the diversity of the subject health information systems and the users that were surveyed across the EU, the study results have a high potential for being extended to similar situations. Nevertheless, the developed models can be customised for newer cases, or the original questionnaires can be reused to feed in a higher number of samples into the models.

Study II also introduces a satisfaction index in the context of health technology, by assigning weights to the three Customer Satisfaction Index (CSI) satisfaction questions, based on the PLS-SEM models. The index can be a quick and rough method to measure the improvement of qualities in a health setting, induced by health information technology intervention.

STUDY III can be considered complementary to study II. While study II focuses on the user satisfaction caused by health information systems and reflected by improvements in qualities, but study III focuses on system-independent and user-specific factors of success. More specifically, it focuses on measuring technophilia in older users (>65) by introducing a short six-item measurement instrument. Through factor analysis of the instrument results, study III reveals two independent factors of techno-enthusiasm and techno-anxiety that together drive user attitude towards health information systems, a prelude to any further success factor. The

study introduces TechPH score, as a weighted sum of the instrument items.

STUDY IV discusses the ethical challenges of evaluating health information systems. It introduces a systematic approach to elicit possible ethical challenges of evaluation by introducing a three-dimensional space, populated by ethical challenges that are elicited from a scoping review or postulation process. The result of the approach is a table of 20 possible ethical challenges, grouped by evaluation stages, involving entities, and affected qualities. These ethical challenges are discussed in the study, providing instantiation and context.

STUDY V recruits outputs and learnings from studies I and II to design a system that partially automates the process of evaluation, makes it continuous and real-time, and replaces hard-to-run surveys with automatically captured indicators and analytics. The study suggests the design of four components. The first one automatically elicits a questionnaire by analysing textual contents created or communicated by users, which reflects their request for outcome qualities. The second component runs the survey based on the elicited questionnaire, according to timings recognised by other components. The third component uses the result of the surveys to run modelling between the requested qualities and user satisfaction. The result of the modelling is captured in a path model structure. The fourth component connects to a database of metrics; automatically measured indicators about users, systems, and their usage patterns; trying to enhance the initial model from the third component. This enhancement involves replacing user-reported outcomes, from the survey, with tacit indicators, from the metrics database, while keeping up with the accuracy of the initial model.

5

Discussion

STUDY I addresses elicitation and organisation of the important qualities that have been impacted by introducing a system into a context. *study I* This approach is beyond just e-health interventions and can be applied in a variety of contexts. The main challenge of this elicitation and organisation is the heterogeneity of qualities.

A question when evaluating qualities is the lingual implications they can carry. In study I, and to some extent in study II, we encountered those challenges and implications. The following lingual challenges might come with those qualities: A word that presents a quality does not necessarily specify the whole boundary of that quality; multiple words might be needed to specify a quality of a single nature. On the other hand, a word might refer to different qualities of a different nature at the same time. There might be different wordings to point to the same quality, and users or frameworks usually follow a protocol or controlled verbs in their communications. Different people might have different understandings about the meanings of words; hence, it is a challenge to calculate the average for their attitudes about a quality. It is not always possible to have exactly the same meaning in the two sides of a translation process. Matching a word with another word in a different language is usually based on subjective similarities.

Did the UVON method succeed in overcoming the challenges mentioned above? The UVON method claims that it can consolidate these different wordings into an ontological structure, clarifying similarities and differences. Validation of the UVON results by the case owners, users in study I, and then by checking analytical validation indicators in study II, showed that method could succeed to some extent, although it should take more cases to prove its capability of creating meaningful

outputs, despite the challenges as mentioned above.

STUDY II identified *effectiveness*, *safety*, and *efficiency* as the most influential qualities in creating satisfaction among patient users. The list for health professionals consists of *effectiveness* and *affordability*. The different ways these two groups perceived the issue is interesting. :study II

Both the patients and health professionals prioritize the *effectiveness*, that is they required first that the e-health applications improve the treatment, in terms such as fewer mistakes, higher degrees of readiness for various situations, or more focused and personalized for the patient. The point is that while we could subjectively measure improvement in treatment by an e-health intervention, but as discussed previously, it is not always easy or possible to objectively measure the clinical impact of that intervention. Running an RCT to detect possible changes in morbidity and mortality is usually out of the scope of most studies on e-health interventions. Conducting RCT needs two large identical populations being observed and avoiding the contamination of the control group. Hence, the quality that has the highest drive for satisfaction is still mostly measurable only through PROMs.

Health professionals' request for *affordability* —and its absence in the most-wanted list by patients— should be considered in the context of the health economy in EU countries. Most EU countries have implemented universal health coverage, with lower percent sourced in the out-of-pocket and higher index of essential service coverage, in comparison to the rest of the world. That means affordability of treatment is not the primary concern of patients. However, health professionals have a different perspective; they reflect more on the financial issues of treatments both at organizational or national levels.

For the two other qualities, *safety* and *efficiency*, it seems that the patients have a more personal perspective. They care more about safety, especially as they might have some degrees of technophobia or lack of general knowledge about the functionality of e-health applications. They have some concerns about unmet safety issues in traditional treatment which can be mitigated by e-health applications, or have some concerns about unmet safety issues in telehealth type of treatment which did not exist in the traditional approach. Similarly, it can be imagined that the problem of long waiting times and the burden of travel time for distant health care facilities hit mainly the patients —not the health professionals— and therefore they care more about efficiency.

IN study III, we focused on a different set of success factors; that is the system-independent and user-specific ones. Study III somehow complements studies I and II in that sense that it retrospects and covers influential factors before any intervention.

This result invites other sorts of activities, such as educating, into the club of activities that can make a system implementation a success case. On the other hand, the study reminds us that not all success factors are controllable. Best of designs might fail if techno-enthusiasm or techno-stress forces do not act in our desired direction. :study III

IN study IV, we propose a method to elicit ethical challenges. The method combines two approaches. Scoping review is the first one, where the second approach focuses on the required qualities of a system, specified by users or a framework. The absence of those qualities or impeding them is considered an ethical challenge. At last, the study introduced a space, consisting of three dimensions of evaluation stages, involving entities, and demanded qualities that helped further postulation of the challenges and at the same time contained them all. Further investigation is needed to learn if this proposed space can be instrumental in discovering ethical challenges in other similar cases. :study IV

By the best of the author's knowledge, this is a novel approach for eliciting ethical challenges. First, the method is not specific to health information systems or even evaluation activities but can be applied to a variety of system usages or activities that study the systems. The method is a systematic approach for exploring possible ethical challenges and might cover blind spots in the detection of those challenges through intuitive approaches.

Second, the method can reveal case-specific challenges. General ethical rules are not local; they are universal or at least belong to some major cultural contexts. However, the instantiation of those rules in a specific context might rise to local and setting-specific situations that need to be discussed in that specific context and setting. The method proposed in IV is capable of opening the door of such discussions.

At last, finding 20 ethical challenges that can be caused or raised by evaluating health information systems, make it clear that evaluation is not a zero-footprint activity, thereby, a code of ethical conduct needs to be defined and applied.

STUDY V is of *design research* type. Unlike traditional research ap-

proaches, parts of a design research study might have different levels of maturity. While some parts represent fully validated and verified designs, there might be parts at the proposition stage. Therefore it is expected that the study proceeds with newer versions with more maturity in parts of the study.

The design proposed in study V is not specific to health information systems; it can be applied in a variety of systems for a semi-automated and continuous evaluation. Practical implementation of the proposed design in a real-world situation in the e-health context can be extended to other contexts. :study V

The last component of study V is based on the idea of replacing indicators which are based on explicit user attitudes by objective behavioural metrics which are *supposed* to represent the user's intentions tacitly. This assumption is challenging. While there is a general tendency in researchers for positivistic measuring, some researchers warn about being biased by evaluating only the *measurable* ones, ignoring the wholistic attitudes. The idea of replacing user attitudes by objective behavioural metrics, such as those recorded in software log files, should be examined closely in practice. It can be imagined that there are some important limitations in applying this approach.

6

Future Works

At least five major directions are emerging from the studies in this manuscript. The first one discusses that evaluation of health information systems should merge with the prognosis of those systems in the context of health setting, extending both scopes of evaluation and prognosis. The second discussion points on the need for automated and continuous evaluation of health information systems; and suggests possible implementation scenarios. The third discussion puts the evaluation of technologies and systems in the context of competing and coexisting technologies and systems. The fourth direction is to make the success factors of systems as design drivers which influence the design from its early stages. The fifth direction expands the meaning of success to the larger landscape of sustainability, giving a broader and deeper definition to evaluation, and assigning newer tasks to evaluators.

6.1 *Evaluation and Prognosis: the Need for a Unified Perspective*

PROGNOSTIC studies, mostly, recruit a traditional set of clinical and biological factors, such as demographics, disease-specific, or co-morbidities, to predict the course of a disease in an individual or population. Also, as a convention, when these factors are supposed to predict the course of a disease without any treatment or with a standard one, then they are considered *prognostic factors*, while in the presence of a health intervention the factors with prediction power are called *predictive factors*.^{65,67} The diversity of interventions entails a higher diversity of predictive factors, in comparison to prognostic factors. Predictive factors can be of different nature rather than the traditional set of clinical or biological ones. For

⁶⁵ Noord 2017

⁶⁶ Clark 2008

⁶⁷ Ballman 2015

example, adherence to treatment, a factor of behavioural nature, can be deterministic in the prediction of the disease outcome, in the presence of a treatment that requires adherence.

In the sake of more accurate predictions, prognostic studies have applied a plethora of advanced technologies, from imaging to machine learning, for projecting the course of diseases such as cancer or dementia.^{68,69} Still, a look at these studies reveals that they are more concentrated on the factors which are shared between both the prognostic and predictive approaches, and less attention has been paid to the predictive factors which are specific to interventions. That is, the predictive factors in those studies are still of clinical or biological nature, and the factors that determine the success of the intervention in a broader social and technical perspective are less considered.

68: Kourou et al. 2015

69: Dallora et al. 2017

HEALTH care system is considered a determinant of health for individuals and communities.⁷⁰⁻⁷² From a broader perspective, there is a range of visible or tacit coordination and organizations of health interventions, whether being considered a part of health care system or not, that embody the health care services upon which our health is dependent. From this range of health care organizations, the *health care system* term usually refers to the health infrastructures, organizations, and resources at macro and national levels, while its incarnation at micro-level is the health settings that an individual has access to them. Therefore, a more generic narration can be that health care systems, settings, and coordinations are determinants of our health. Corollary to this narration, it is the accessibility, performance, and quality of those systems and settings, in all of their variations, that majorly determines our health status as individuals or populations.

70: McKeown et al. 1972

71: Glouberman et al. 2003

72: World Health Organization 2007

All across variations of health care installations and settings, health technologies are the backbones upon which the whole mass of the systems stand up. The wide breadth and inclusive definition of health technology⁹ give leeway to claim that the performance of health care systems and settings, at any level, is highly dependent on the performance of the backbone health technologies that support creation and delivery of health care service through those health care systems.

Among the diversity of health technologies, health information technologies have become essential parts of health care systems and settings today.⁷² More and more corroborations are reported, supporting the positive impact of health information technologies on health outcomes.^{36,73}

73: Buntin et al. 2011

In consequence, the dependence of health to health systems is extended to the underlying basis, that is health technology and its incarnation as the variety of health-related technical systems. Therefore, the prognosis of an individual's health, in the presence of a novel or traditional intervention as it is expected in real life, is dependent on the prognosis of the underlying health technologies and socio-technical systems that are engaged.

PROGNOSIS of health care socio-technical systems is usually articulated through other wordings rather than *prognosis*. We usually express our prediction and prognosis about those systems by evaluations, where the projection of the future is an embodied element. Evaluations are the prediction of how their subject systems and their provided health care are accessible, available, effective, secure, efficient, and how they will provide other relevant qualities.³⁵ Evaluations, especially the summative ones, are pointless if they cannot bear their validity for a short or long term future.

Health information systems, as a subset of health-related socio-technical systems, can typify how evaluation is a form of prognosis. While the evaluation frameworks might lack a consensus on what to evaluate,^{74,75} or they take a dynamic approach in defining what to evaluate.⁵⁸ However, the evaluation aspects mentioned in those frameworks or the output of their applications usually have a prognostic notion, and they lead to prognostic outcomes. In Table 6.1, examples of these notions and outcomes are presented. The qualities on the left side of the table are those extracted from the FI-STAR project.⁵⁸ The prognostic impacts on the right side of the table are of conjecture nature, for the outcomes studied rigorously one should consult with the studies about the clinical impact of health information technologies.^{36,76}

74: Eslami Andargoli et al. 2017

75: Klecun-Dabrowska et al. 2001

76: Wu et al. 2006

To conclude: prognostic studies that study the course of disease in the presence of treatment should be extended to include the prognosis of the health technologies and systems that have been used in the corresponding health setting. This extension can happen by running health technology evaluation studies.

A unified perspective for prognostic and evaluation studies can fulfil the ultimate mission of prognosis in a more holistic and contemplative manner. Evaluation studies gain more value than before if they get connected to prognosis studies.

Quality	Possible Impact on Prognosis
Satisfaction	Higher adoption →Higher number of applications of a better intervention →Longer survival or lower morbidity rates
Accessibility	More patients or professionals can use the system →Higher number of applications of a better intervention →Longer survival and lower mortality or morbidity rates
Adherence	Higher rate of successful treatments →Longer survival and lower mortality or morbidity rates
Affordability	More inclusion →Longer survival and lower mortality or morbidity rates Frees up the budget for other health interventions →Better but more expensive treatments become feasible →Longer survival and lower mortality or morbidity rates
Availability	Less denial of service →Longer survival and lower mortality or morbidity rates
Efficiency	Better allocation of limited health resources →Higher inclusion of patient population →Longer survival and lower mortality or morbidity rates
Effectiveness:	Higher rate of successful treatments →Longer survival and lower mortality or morbidity rates
Empowerment	Better control of the cases by the patient or professional →Longer survival and lower mortality or morbidity rates
Safety	Not adding to or amplifying the risks →Maintaining the same survival, mortality, and morbidity rates More safe treatments →Longer survival and lower mortality or morbidity rates
Trustability	Higher adoption →Higher number of applications of a better intervention →Longer survival and lower mortality or morbidity rates

Table 6.1: Significance of quality to success relations.

6.2 Automated and Continuous Evaluation

IN study V we proposed the design of a semi-automated and continuous evaluation system. Parts of this design still need to be implemented. For example, automating the evaluation process by automated implementation of UVON, using text analytics, and incrementally replacing explicit user feedbacks by their tacit opinion expressed in automatically measurable indicators. Also, component IV in this design needs implementation and validation.

6.3 Total Technology Adoption

LOOKING at the publication of health informatics journals, one can withstand that the number of e-health applications that have a chance to be reported and evaluated in a scientific paper is considerable. One can imagine the total number of e-health applications being run in real-life should be much more. Almost all of these studies focus on evaluating and reporting on specific e-health applications in specific contexts. What they usually miss, is the success of those applications when introduced in an environment already saturated by a plethora of other e-health applications.

:how to measure the success of a system in the presence of other systems?

Techno-stress is a known concept in the literature of technology acceptance⁷⁷ and user satisfaction.⁷⁸ E-health applications, like most of the other information systems, take a share of our limited capacity to interact with devices. Any e-health application is opaque for our mind to some extent; it allocates a part of our cognitive capacity to themselves. An extended evaluation of e-health applications needs to consider this limit.

:limits to our cognitive capacity to interact with various systems

77: Raitoharju 2005

78: Tarafdar et al. 2010

6.4 Design for Success

HOW can one traceback the success factors of a health information system to specific features in the system, coordinations in the health setting, or education of its users? The ultimate outcome of an evaluation can be to provide learning materials for future actions and designs. Finding a way to recreate evaluation results as design guidelines, feature requests, and setting or preparation recommendations employs evaluation outcomes in the right way.

6.5 *Sustainability of Health Information Systems*

THE success of a system cannot be a short-term situation. A successful system should experience a reasonably-long course of life. In a health setting, health information systems, like any other product, go through a course of life-cycle where eventually they get retired and replaced by brand newer systems. Though, the path of this course is not necessarily straightforward. A health setting might reject a health information system, probably reflecting by the low number of acceptance, for various reasons. The rejection might cause reverting to the previous situation or seeking a new solution. Then it comes the question of what is the difference between being retired or being rejected? How long should a system perform in a health setting to be considered a successful system?

The success of a system is situation that is the child of an over-arching concept of sustainability. A sustainable system can sustain its success for a determined period, and it does not disrupt the vital characteristics of the whole setting or ecosystem. Sustainability of a system is only partially dependent on the traditional success indicators such as satisfaction and acceptance of the system by its users, but the system also needs to qualify in other aspects. A sustainable system should deliver not only the same set of functionalities but also the same amount of value-added. It is possible that a system maintains the same degree of delivery in functionality but fails in delivering the same level of added value, due to changes in the environment, standards or users' demands.

To maintain the same level of value, a sustainable system needs to upgrade its functionality continuously. However, there are usually points in the timeline where being replaced by a brand new system is more affordable, efficient, and effective. These points should be far from the commence of the system, and preferably being anticipated in advance.

As retiring and replacing a health information system is inevitable, a successful system should be defined as the one that makes it smooth and practical. It is important how the parts of the system can be reused or how the data can be recycled. The system should be loosely coupled to other elements of the health setting or health care ecosystem, allowing a smooth replacement.

Summary Points

Focus

- What are the extensions and future works to the studies done

Key Messages

- Health prognosis of an individual is interwoven with the prognosis of his health care setting. Evaluation of the underlying health technology in the setting provides the prognosis for the latter part and should be included in the sake of a more holistic approach.
- Prognostic and technology evaluation studies are of a similar nature. Prognostic studies can be enriched by considering health technology evaluation studies. *Automated and continuous evaluation mechanism is the next step for models and frameworks of evaluation in health information systems.
- Success of a system should be investigated in the context of parallel usage, competing, and coexistence with other technologies and systems. *Success factors can perform as drivers for design. They can lead, inspire, and prioritize features. *The concept of success in health information systems should be expanded and enhanced by sustainability

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PART II

PAPERS

8

Evaluating Health Information Systems Using Ontologies

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Abstract

Background There are several frameworks that attempt to address the challenges of evaluation of health information systems by offering models, methods, and guidelines about what to evaluate, how to evaluate, and how to report the evaluation results. Model-based evaluation frameworks usually suggest universally applicable evaluation aspects but do not consider case-specific aspects. In the other hand, evaluation frameworks that are case-specific, by eliciting user requirements, limit their output to the evaluation aspects suggested by the users in the early phases of system development. Also, these case-specific approaches extract different sets of evaluation aspects from each case, making it challenging to collectively compare, unify, or aggregate the evaluation of a set of heterogeneous health information systems.

Objectives The aim of this paper is to find a method capable of suggesting evaluation aspects for a set of one or more health information systems—whether similar or heterogeneous—by organizing, unifying, and aggregating the quality attributes

extracted from those systems and from an external evaluation framework.

Method Based on the available literature in semantic networks and ontologies, a method (called UVON) was developed that can organize, unify, and aggregate the quality attributes of several health information systems into a tree-style ontology structure. The method was extended to integrate its generated ontology with the evaluation aspects suggested by model-based evaluation frameworks. An approach was developed to extract evaluation aspects from the ontology that also considers evaluation case practicalities such as the maximum number of evaluation aspects to be measured or their required degree of specificity. The method was applied and tested in FI-STAR, a project of seven cloud-based e-health applications that were developed and deployed across European Union countries.

Results The relevance of the evaluation aspects created by the UVON method for the FI-STAR project was validated by the corresponding stakeholders of each case. These evaluation aspects were extracted from a UVON-generated ontology structure that reflects both the internally declared required quality attributes in the seven e-health applications of the FI-STAR project and the evaluation aspects recommended by the MAST evaluation framework. The extracted evaluation aspects were used to create questionnaires (for the corresponding patients and health professionals) in order to evaluate each individual case and the whole of the FI-STAR project.

Conclusions The UVON method can provide a relevant set of evaluation aspects for a heterogeneous set of health information systems by organizing, unifying, and aggregating the quality attributes through ontological structures. Those quality attributes can be either suggested by evaluation models or elicited from the stakeholders of those systems in the form of system requirements. The method continues to be systematic, context-sensitive, and relevant across a heterogeneous set of health information systems.

Keywords

Health Information Systems; Ontologies; Evaluation; Technology Assessment; Biomedical

8.1 Introduction and Background

IN one aspect at least, the evaluation of health information systems matches well with their implementation: they both fail very often.¹⁻³ Consequently, in the absence of an evaluation that could deliver insight about the impacts, an implementation cannot gain the necessary accreditation to join the club of successful implementations. Beyond the reports in the literature on the frequent accounts of this kind of failure,³ the reported gaps in the literature,⁴ and newly emerging papers that introduce new ways of doing health information system evaluation,⁵ including this paper, can be interpreted as a supporting indicator that the attrition war on the complexity and failure-proneness of health information systems is still ongoing.⁶ Doing battle with the complexity and failure-proneness of evaluation are models, methods, and frameworks that try to address what to evaluate, how to evaluate, or how to report the result of an evaluation. In this front, this paper tries to contribute to the answer to *what to evaluate*.

1: Littlejohns et al. 2003

2: Kreps et al. 2007

3: Greenhalgh et al. 2010

4: Chaudhry et al. 2006

5: Yusof et al. 2008

6: Yusof et al. 2008

STANDING as a cornerstone for evaluation is our interpretation of what things constitute success in health information systems. A body of literature has developed concerning the definition and criteria of a successful health technology, in which the criteria for success go beyond the functionalities of the system.^{7,8} Models similar to Technology Acceptance Model (TAM), when applied to health technology context, define this success as the end-users' acceptance of a health technology system.⁹ The success of a system, and hence the acceptance of a health information system, can be considered the use of that system when using it is voluntary, or it can be considered the overall user acceptance when using it is mandatory.^{10,11}

:user-based success criteria

7: Holden et al. 2010

8: Berg 2001

9: Hu et al. 1999

10: Goodhue et al. 1995

11: Ammenwerth et al. 2006

12: Ekland et al. 2012

To map the definition of success of health information systems onto real world cases, certain evaluation frameworks have emerged.^{6,12} These frameworks, with their models, methods, taxonomies, and guidelines,

are intended to capture parts of our knowledge about health information systems. This knowledge enables us to evaluate those systems, and it allows for the enlisting and highlighting of the elements of evaluation processes that are more effective, more efficient, or less prone to failure. Evaluation frameworks, specifically in their summative approach, might address what to evaluate, when to evaluate, or how to evaluate.⁶ These frameworks might also elaborate on evaluation design, the way to measure the evaluation aspects, or how to compile, interpret, and report the results.¹³

13: Talmon et al. 2009

Evaluation frameworks offer a wide range of components for designing, implementing, and reporting an evaluation, among which are suggestions or guidelines for finding out the answer to *what to evaluate*. The answer to *what to evaluate* can range from the impact on structural or procedural qualities to more direct outcomes such as the overall impact on patient care.¹⁴ For example, in the STARE-HI statement, which provides guidelines for the components of a final evaluation report of health informatics, the “outcome measures or evaluation criteria” parallel the *what to evaluate* question.¹³

14: Ammenwerth et al. 2004

To identify evaluation aspects, evaluation frameworks can take two approaches: top-down or bottom-up. Frameworks that take a top-down approach try to specify the evaluation aspects through instantiating a model in the context of an evaluation case. Frameworks that focus on finding, selecting, and aggregating evaluation aspects through interacting with users, i.e., so-called user-centered frameworks, take a bottom-up approach.

:top-down or bottom-up approach

In the model-based category, TAM and Extended Technology Acceptance Model (TAM2) have wide application in different disciplines including health care.⁷ Beginning from a unique dimension of *behavioral intention to use (acceptance)*, as a determinant of success or failure, the models go on to expand it to *perceived usefulness* and *perceived ease of use*,^{7,15} where these two latter dimensions can become the basic constructs of the evaluation aspects. The Unified Theory of Acceptance and Use of Technology (UTAUT) framework introduces four other determinants: *performance expectancy*, *effort expectancy*, *social influence*, and *facilitating conditions*.¹⁶ Of these, the first two can become basic elements for evaluation aspects, but the last two might need more adaptation to be considered as aspects of evaluation for a health information system.

15: Davis 1989

16: Venkatesh et al. 2003

Some model-based frameworks extend further by taking into consideration the relations between the elements in the model. The Fit

between Individuals, Task and Technology (FIT^T) model includes the *task* element beside the *technology* and *individual* elements. It then goes on to create a triangle of “fitting” relations between these three elements. In this triangle, each of the elements or the interaction between each pair of elements is a determinant of success or failure¹¹); therefore, each of those six can construct an aspect for evaluation. The Human, Organization, and Technology Fit (HOT-fit) model builds upon the DeLone & McLean Information Systems Success Model¹⁷ and extends further by including the *organization* element beside the *technology* and *human* elements.⁵ This model also creates a triangle of “fitting” relations between those three elements.

17: DeLone et al. 2004

Outcome-based evaluation models, such as the Health IT Evaluation Toolkit provided by the Agency for Healthcare Research and Quality (AHRQ), consider very specific evaluation measures for evaluation. For example, in the above-mentioned toolkit, measures are grouped in domains, such as *efficiency*, and there are suggestions or examples for possible measures for each domain, such as *percent of practices or patient units that have gone paperless*.¹⁸

18: Cusack et al. 2007

In contrast to model-based approaches, bottom-up approaches are less detailed on about the evaluation aspects landscape; instead, they form this landscape by what they elicit from stakeholders. Requirement engineering, as a practice in system engineering and software engineering disciplines, is expected to capture and document, in a systematic way, user needs for a to-be-produced system¹⁹). The requirements specified by requirement documents, as a reflection of user needs, determine to a considerable extent what things need to be evaluated at the end of the system deployment and usage phase, in a summative evaluation approach. Some requirement engineering strategies apply generic patterns and models to extract requirements,¹⁹ thereby showing some similarity, in this regard, to model-based methods.

19: Cheng et al. 2007

The advantages of elicitation-based approaches, such as requirement engineering, result from an ability to directly reflect the case-specific user needs in terms of functionalities and qualities. Elicitation-based approaches enumerate and detail the aspects that need to be evaluated, all from the user perspective. Evaluation aspects that are specified through the requirement engineering process can be dynamically added, removed, or changed due to additional interaction with users or other stakeholders at any time. The adjustments made, such as getting more detailed or more generic, are the result of new findings and insights, new priorities,

or the limitations that arise in the implementation of the evaluation.

The advantages in the requirement engineering approach come at a cost of certain limitations compared to model-based methods. Most of the requirement elicitation activities are accomplished in the early stages of system development, when the users do not have a clear image of what they want or do not want in the final system²⁰). However, a model-based approach goes beyond the requirements expressed by the users of a specific case by presenting models that are summaries of past experiences in a wide range of similar cases and studies.

20: Friedman et al. 2006

BEING case-specific by using requirement engineering processes has a side effect: the different sets of evaluation aspects elicited from each case, which can even be mutually heterogeneous. Model-based approaches might perform more uniformly in this regard, as they try to enumerate and unify the possible evaluation aspects through their models imposing a kind of unification from the beginning. However, there still exists a group of studies asking for measures to reduce the heterogeneity of evaluation aspects in these approaches.¹²

:the challenge of comparing heterogeneous things

Heterogeneity makes evaluation of multiple cases or aggregation of individual evaluations a challenge. In a normative evaluation, comparability is the cornerstone of evaluation²¹), in the sense that things are supposed to be better or worse than one another or than a common benchmark, standard, norm, average, or mode, in some specific aspects. Without comparability, the evaluation subjects can, at best, only be compared to themselves in the course of their different stages of life (longitudinal study).

21: Bürkle et al. 2001

In health technology, the challenge of heterogeneity for comparing and evaluation can be more intense. The health technology assessment literature applies a very inclusive definition of *health technology*, which results in a heterogeneous evaluation landscape. The heterogeneity of evaluation aspects is not limited to the heterogeneity of actors and their responses in a health setting; rather, it also includes the heterogeneity of health information technology itself. For example, the glossary of health technology assessment by INAHTA describes health technology as the “pharmaceuticals, devices, procedures and organizational systems used in health care.”²² This description conveys how intervention is packaged in chemicals, supported by devices, organized as procedures running over time, or structured or supported by structures in organizational systems. Similarly inclusive and comprehensive definitions can be found in other

:heterogeneity of health technology in definition level

22: Facey et al. 2006

studies.^{23,24} This heterogeneous evaluation context can create problems for any evaluation framework that tries to stretch to accommodate a diverse set of health technology implementations. This heterogeneity can present challenges for an evaluation framework in comparing evaluation aspects²⁵ and, consequently, in summing up reports²⁶ as well as in the creation of unified evaluation guidelines, and even in the evaluation of the evaluation process.

23: Kristensen 2009

24: Draborg et al. 2005

25: Busse et al. 2002

26: Lampe et al. 2009

By extracting the lowest common denominators from among evaluation subjects, thereby creating a uniform context for comparison and evaluation, we can tackle the challenge of heterogeneity via elicitation-based evaluation approaches. Vice versa, the evaluation aspects in an evaluation framework suggest the common denominators between different elements. The lowest common denominator, as its mathematical concept suggests, expands to include elements from all parties, where the expansion has been kept to the lowest possible degree.

:evaluation aspects as the lowest common denominators of the evaluation objects

Usually, there are trade-offs and challenges around the universality of an evaluation aspect related to how common it is and its relativeness (i.e., how low and close to the original elements it lies). When the scopes differ, their non-overlapped areas might be considerable, making it a challenge to find the common evaluation aspects. Furthermore, the same concepts might be perceived or presented differently by different stakeholders.²⁷ Also, different approaches usually target different aspects to be evaluated, as a matter of focus or preference.

27: Ammenwerth et al. 2003

It is possible to merge the results of model-centered and elicitation-centered approaches. The merged output provides the advantages of both approaches while allowing the approaches to mutually cover for some of their challenges and shortcomings.

:solution: merging the approaches

IN Future Internet Social and Technological Alignment Research (FI-STAR), as well as other similar health information systems comprised of multiple applications, it can be challenging to find a unified evaluation approach for the different quality attributes in those application. Each application exposes a different set of value cases and quality attributes. The evaluation of all these diversified use-cases clearly demands a method for *unification* of the aspects, which enables comparing the applications with each other and aggregating the individual assessments into a unified one. Regarding the future possible expansions of the FI-STAR, this unification should be dynamic and adaptable, being able to accommodate new evaluation requirements introduced by new cases. The detection

and unification of evaluation aspects should be homogeneous along the time, especially when it is accommodating new cases; therefore it should be methodical to be repeatable with reasonably homogeneous results.

THE aim of this paper is to address the question of *what to evaluate* in a health information system by proposing a method (called Unified eValuation using ONtology) which constructs evaluation aspects by organizing quality attributes in ontological structures. The method deals with the challenges of model-based evaluation frameworks by eliciting case-specific evaluation aspects, adapting and integrating evaluation aspects from some model-based evaluation frameworks and accommodating new cases that show up over time. The method can address heterogeneity by unifying different quality attributes that are extracted from one or more evaluation cases. This unification is possible with some arbitrary degree of balance between similarities and differences with respect to the needs of evaluation implementation. As a proof of the applicability of the proposed method, it has been instantiated and used in a real-world case for evaluating health information systems.

:summary of contributions

The structure of the rest of this paper follows. The research method that resulted in the Unified eValuation using ONtology (UVON) method is described in Section 8.2. The result, i.e., the UVON method, is covered in Section 8.3.1, while its application in the context project is covered in Section 8.3.2. The rationale behind the method is discussed in Section 8.4, and the possible extensions and limitations are found in Sections 8.4.1 and 8.4.2. The Section 8.5 summarizes the conclusions of the paper.

:paper structure

8.2 Method and Materials

THE FI-STAR project is a pilot project in e-health systems funded by the European Union (EU). The evaluation of the FI-STAR project has been the major motive, the empirical basis, and the testbed for our proposed evaluation method, i.e., the UVON method (to be described in Section 8.3). FI-STAR is a project within the Future Internet Public-Private Partnership (FI-PPP) and relates to the Future Internet (FI) series of technology platforms. The project consists of seven different e-health cloud-based applications being developed and deployed in seven pilots across Europe. Each of these applications serves a different community of patients and health professionals²⁸ and has different expected clinical

:the FI-STAR project

28: FI-STAR Consortium
2014

outcomes. FI-STAR and its seven pilot projects rose to the challenge of finding an evaluation mechanism that can be utilized both to evaluate each project as well as to aggregate the result of those evaluations as an evaluation of the whole FI-STAR project.

A general review of the existing evaluation frameworks was done. Existing model-based evaluation frameworks, which usually suggest universal quality attributes for evaluation, could not cover all the quality attributes (i.e., evaluation aspects) reflected by the requirement documents of the pilot projects in FI-STAR. Even if there was a good coverage of the demanded evaluation aspects, there was still no guarantee that they could maintain the same degree of good coverage for the future expansions of the FI-STAR project. On the other hand, the requirement documents from the FI-STAR project were not expected to be the ultimate sources for identifying those quality attributes. It was speculated that there could exist other relevant quality attributes that were captured in the related literature or embedded in other, mostly model-based, health information system evaluation frameworks. For these reasons, it was decided to combine quality attributes both from the FI-STAR sources and a relevant external evaluation framework. In order to find other relevant evaluation aspects, a more specific review of the current literature was performed that was more focused on finding an evaluation framework of health information systems that sufficiently matched the specifications of the FI-STAR project. The review considered the Model for ASsessment of Telemedicine applications (MAST) framework²⁹ as a candidate evaluation framework. This evaluation framework was expected to cover the quality attributes that were not indicated in the FI-STAR requirement documents but that were considered necessary to evaluate in similar projects. These extra quality attributes are suggested by expert opinions and background studies.²⁹ Nevertheless, it was necessary to integrate the quality attributes extracted from this framework with the quality attributes extracted from the FI-STAR requirement documents.

29: Kidholm et al. 2012

Regarding the heterogeneity of FI-STAR's seven pilot projects, an evaluation mechanism was needed to extract common qualities from different requirement declarations and unify them. A review of the related literature showed that the literature on ontologies refers to the same functionalities, i.e., capturing the concepts (quality attributes in our case) and their relations in a domain.³⁰ It was considered that sub-class and super-class relations and the way they are represented in ontology

30: Noy et al. 2001

unify the heterogeneous quality attributes that exist in our evaluation case. For the purposes of the possible future expansions of the FI-STAR project, this utilization of ontological structures needed to be systematic and easily repeatable.

8.3 Results

A method was developed to organize and unify the captured quality attributes via requirement engineering into a tree-style ontology structure and to integrate that structure with the recommended evaluation aspects from another evaluation framework. The method was applied for the seven pilots of the FI-STAR project, which resulted in a tree-style ontology of the quality attributes mentioned in the project requirement documents and the MAST evaluation framework. The top 10 nodes of the tree-style ontology were chosen as the 10 aspects of evaluation relevant to the FI-STAR project and its pilot cases.

:the resulted ontology and the top 10 nodes

8.3.1 The UVON Method for Unifying the Evaluation Aspects

METHODICAL capture of a local ontology³¹ from the quality attributes, i.e., evaluation aspect ontology, and reaching unification by the nature of its tree structure is the primary strategy behind our method. Therefore, the UVON method is introduced, so named to underline *Unified eValuation* of aspects as the target and *ONtology* construction or integration as the core algorithm. The ontology construction method presented in this paper is a simple, semi-automated method, configured and tested against FI-STAR project use cases. The UVON method does not try to introduce a new way of ontology construction; rather, it focuses on how to form a local ontology^{31,32} out of the quality attributes of a system and utilize it for the purpose of finding out what to evaluate. In this regard, the ontology construction in the UVON method is a reorganization of common practices, such as those introduced by 2001.

31: Uschold 2000

32: Choi et al. 2006

THE ontology structure, in its tree form, is the backbone of the UVON method. Modern ontology definition languages can show different type of relations, but for the sake of our method here, we only use the *is of type* relation. The *is of type* relation can also describe pairs such as parent and child, super-class and sub-class, or general and specific relations. This kind of relation creates a direct acyclic graph structure which is or can be

:case-specific considerations in the method

converted to a tree form. In this tree, the terms and concepts are nodes of the tree. The branches consist of those nodes connected by *is of type* relations. The tree has a root, which is the super-class, parent, or the general form of all other nodes. Traditionally, this node has been called the *thing*.³⁰

Figure 8.2 is an example of how this ontology structure can look. All the nodes in this picture are quality attributes, except the leaf nodes at the bottom, which are instances of health information systems. While going up to the top layers in the ontology, the quality attributes become more generic, at the same time aggregating and unifying their child nodes.

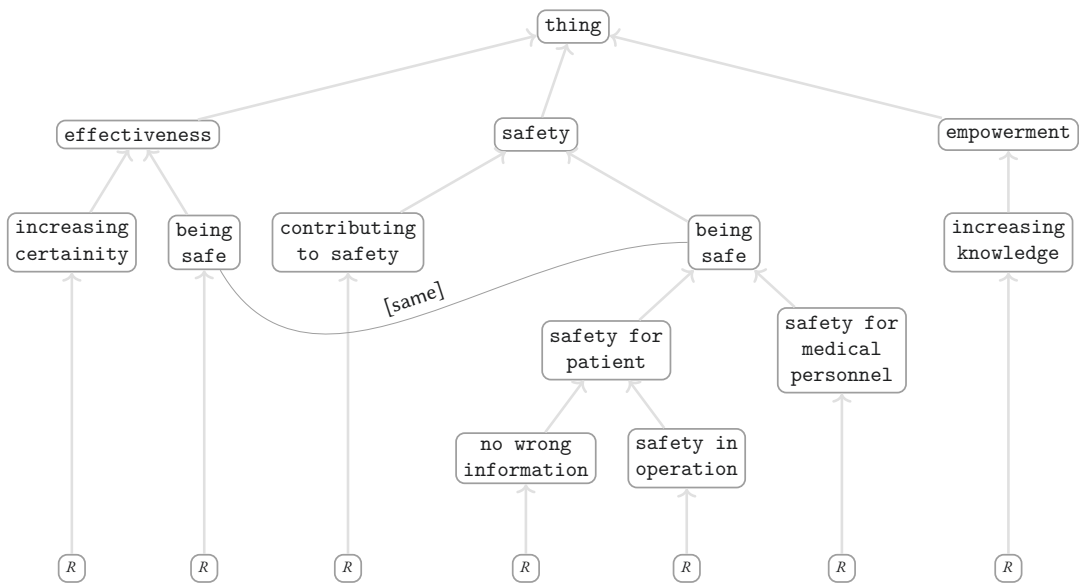


Figure 8.2: An example snapshot of the output ontology while running the UVON method

THE UVON method is composed of three phases: α , β , and γ (Figure 8.3). In the first phase, all quality attributes elicited by the requirement engineering process are collected in an unstructured set that is respectively called α set. In the next phase (β), based on the α set, an ontology is developed by the UVON method, which is called β (beta) ontology. In the next step, if the ontology is extended by an external evaluation framework (as discussed in the method), then it is called γ (gamma) ontology.

:construction of the β ontology

THE β ontology construction begins with a special initial node (i.e., quality attribute) that is called *thing*. All the collected quality attributes are going to begin a journey to find their position in the ontology structure, beginning from the *thing* node and going down the ontology structure to certain points specified by the algorithm. This journey is actually a depth-first tree traversal algorithm³³ with some modifications. To avoid confusion in the course of this algorithm, a quality attribute that seeks to find its position is called a *traveling quality attributes* or Q_t .

33: Tarjan 1972

The first quality attribute simply needs to add itself as the child of the *thing* root node. For the remaining quality attributes, each checks to see if there exists any child of the *thing* node, where the child is a super-class (superset, super-concept, general concept, more abstract form, etc.) with regard to the traveling quality attribute (Q_t). If such a child node (quality attribute) exists (let's say Q_n) then the journey continues by taking the route through that child node. The algorithm examines the children of Q_n (if any exist) to see if it is a sub-class to any of them (or they are super-class to Q_t).

The journey ends at some point because of the following situations: If there is no child for a new root quality attribute (Q_n), then the traveling quality attribute (Q_t) should be added as a child to this one and its journey ends. That is the same if there exist children to a new root quality attribute (Q_n), but none of them is a super-class and nor a sub-class to our traveling quality attribute. Beside these two situations, it is possible that no child is a super-class, but one or more of them are the sub-class of the traveling quality attribute (Q_t). In this situation, the traveling quality attribute (Q_t) itself becomes a child of that new root quality attribute, and those child quality attributes move down to become children of the traveling quality attribute (Q_t).

To keep the ontology as a tree, if a traveling quality attribute (Q_t) finds more than one super-class child of itself in a given situation, then it should replicate (fork) itself into instances, as many as the number of those children, and go through each branch separately. It is important to note that, logically, this replication cannot happen over two disjoint (mutually exclusive) branches.

It is also possible to inject new quality attributes in between a parent node and children, but only if it does not break sub-class or super-class relations. This injection can help to create ontologies in which the nodes at each level of the tree have a similar degree of generality, and each branch of the tree grows from generic nodes to more specific ones.

This customized depth-first tree traversal algorithm, which actually constructs a tree-style ontology instead of just traversing one, is considered semi-automated, as it relies on human decision in two cases. The first case is when it is needed to consider the super-class to sub-class relations between two quality attributes. The gradual development of the ontology through the UVON method spreads the decision about super-class to sub-class relations across the course of ontology construction. The unification of heterogeneous quality attributes (nodes) is the result of accumulating these distributed decisions which are embodied as super-class to sub-class relations. Each of these relations (i.e., decisions) makes at least two separate quality attributes closer together by representing them through more generic quality attributes.

Also, one can inject a new quality attribute to the ontology tree, even though that quality attribute is not explicitly mentioned in the requirement documents. This injection is only allowed when that quality attribute summarizes or equals a single or a few sibling quality attributes that are already in the ontology. The injection can improve clarity of the ontology. It can also help adjust the branches of the ontology tree to grow to a certain height, which can be helpful when a specific level of the tree is going to be considered as the base for creating a questionnaire. This adjustment of branch height might be needed if a branch is not tall enough to reach a specific level, meaning none of the quality attributes in that branch gets presented in the questionnaire. In addition, if a quality attribute is very specific compared to other quality attributes in that level of the tree, the questions in the questionnaire become inconsistent in their degree of generality. This inconsistency can be handled by injecting more generic quality attributes above the existing leaf node in the branch. All the above mentioned benefits come with the cost of subjectivity in introducing a new quality attribute.

THE γ phase ontology is constructed the same as the β phase, but it adds materials (quality attributes) from external sources. In this sense, the quality attributes specified in an external evaluation framework, probably a model-based one, should be extracted first. Those quality attributes should be fed into the β ontology the same as other quality attributes during the β phase. The UVON method does not discriminate between quality attribute by the origin, but it might be a good practice to mark those quality attributes originally from the external evaluation framework if we need later to make sure they are used by their original names

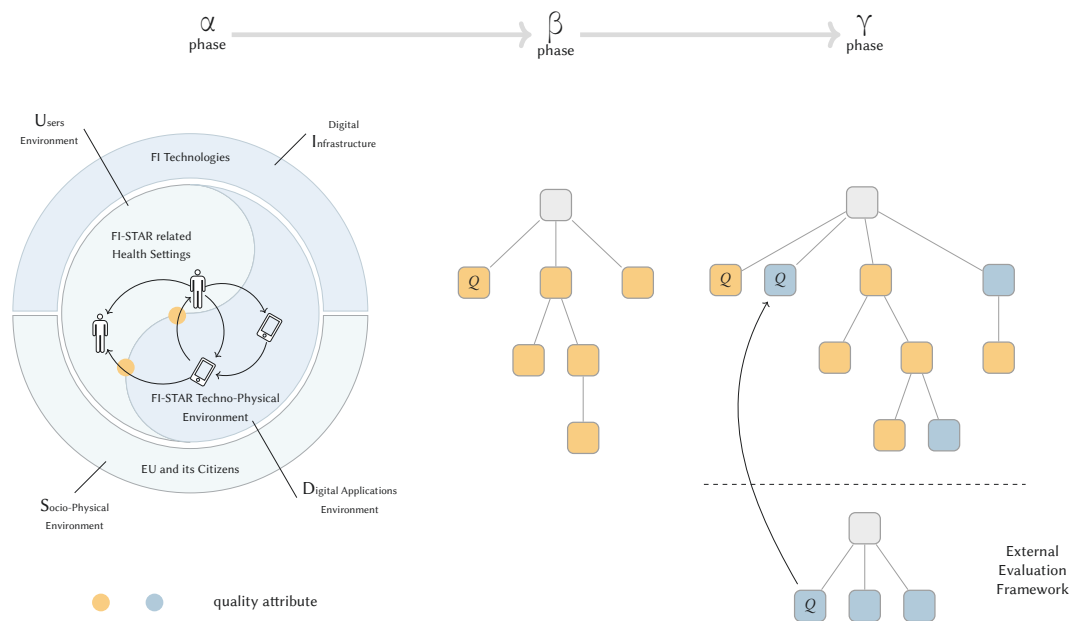


Figure 8.3: Ontology construction for a health information system

in the summarizing level (to be discussed in the following paragraphs).

EACH level of the resulting ontology tree(s) —except those that are deeper than the length of the shortest branch— represents or summarizes quality attributes of the whole system in some degree of generality or specificity. That of the *root* node is the most general quality attribute, which is too general to be useful for any evaluation; as for the levels below, each gives a view of the quality attributes in the whole system. As each parent node represents a general form of its children, each level summarizes the level below. We refer to one of these levels of the ontology tree that is considered for creating a questionnaire as the *summarizing level*.

:the summarizing level

The quality attributes in each of the other levels (such as L_1 in Figure 8.5) can be evaluation aspects (i.e., the answer to *what to evaluate*) that can be measured by a questionnaire or other measurement methods. Also, depending on the measuring method, the level below the summarizing level can be used to give details for each of the evaluation aspects.

The practicalities of measurement in a case determine which summa-

rizing level to choose. Levels closer to the root can be too abstract while deeper levels can be too detailed. Also, the number of quality attributes in a level can impact which level is appropriate. In the FI-STAR project, the limitation on the number of questions in the questionnaire was a determinant for selecting the summarizing level, where only level 2 fit the project limitations (although level 3 helped to make each question more detailed). It is possible to grow a short branch by adding a chain of children that are the same as their parents to make the branch reach a specific level, thereby making that level selectable as a summarizing level.

8.3.2 *Result of the UVON Method Application in the FI-STAR Project*

HARVESTING the value-cases and requirement documents for all seven trial-cases in the FI-STAR project provided the initial set of quality attributes, i.e., the α set. Several quality attributes were redundant or similar, but it was left to the UVON method to unify them. There were also several quality attributes with the same wording but different conceptual indications in their respective usage contexts. These quality attributes we added to the α set with small modifications to differentiate them from each other. For example, two different references to *efficiency* were converted to *efficiency by reducing complexity* and *efficiency by reducing time*.

In the next step, i.e., β phase, the UVON method developed β ontology by using the α set. The redundant quality attributes were integrated into single entities, while other quality attributes were grouped by their direct or indirect parents in the ontology structure regarding their degree of similarity or dissimilarity.

Also, it was noticed that quality attributes are preferred—though, not necessarily always—to be noun phrases rather than adjective phrases; this is because fulfilling a quality attribute expressed in an adjective phrase could imply that all of its child quality attributes need to be fulfilled. For example, to fulfill the quality of being *safe*, it is required to be both *safe for patient* and *safe for medical personnel*. This is in contrast to the *child is type of parent* relations that exist between the ontology entities. But, if we consider the noun form (noun phrase), e.g., *safety* rather than *safe*, then *safety for patient* and *safety for medical personnel* are all subtopics of *safety*; hence, that would be correct and more intuitive. Also, considering that each node in the ontology is an aspect for evaluation can

make deciding parent-child relations more straightforward. For example, the *safety* node should be read as *safety aspect*, and its child should be read as *safety for patient aspect*.

Applying the UVON method in its β and γ phases, respectively, created the β and γ ontology structures. The first ontology structure (β) is based on the α set of collected quality attributes, whereas the second one (γ) extends the β ontology by integrating the MAST framework evaluation aspects (grouped as domains) as specified by MAST.²⁹ Here, “integration is the process of building an ontology in one subject reusing one or more ontologies in different subjects”.³⁴ In this sense, γ ontology is constructed by mapping, aligning, or merging³⁵ the ontological representation of the external framework evaluation aspects (MAST in our case) to the β ontology. The result of the integration is shown in Table 8.3.

34: Pinto et al. 2001

35: Abels et al. 2005

The MAST framework specifies 7 evaluation domains, where each contains several topics (aspects or sub-aspects).²⁹ Due to the FI-STAR project requirements, we ignored *clinical effectiveness* and *socio-cultural, ethical, and legal* domains (These were the job of other teams). One other domain, *health problem and description of the application* as well as some aspects in other domains could not be considered as quality attributes and were removed from the process. The remaining four domains that were fed into the UVON method are *safety*, *patient perspectives*, *economic aspects*, and *organizational aspects*. There was an interesting observation, a possible motivation for further investigations: the aspects in those four domains overlap considerably with the evaluation aspects that were elicited from FI-STAR users and formed into an ontology by the UVON method.

Both the β and γ ontology structures were described in Web Ontology Language (OWL) using Protégé version 4.x software. OWL, as an ontology language, can describe a domain of knowledge through its lingual elements and their relations.³⁶ In OWL, there exist *individuals*, *classes*, *class relations*, *individual relations*, and *relation hierarchies*.³⁷ In FI-STAR ontology structures, the individuals were mapped to the use-cases in the FI-STAR project; classes were used to represent quality attributes (i.e., the evaluation aspects); and class relations became the hierarchal relations between quality attributes (i.e., *is of type* or the super-class to sub-class relations). Individual relations and relation hierarchies were not utilized.

36: Bechhofer 2009

37: Hitzler et al. 2012

Some generic nodes were inserted in order to group sibling nodes that were conceptually closer together in the ontology structure. If a

quality attribute was connected to two different branches, it was forked and presented in the both branches (as described before); that keeps the ontology in a tree structure rather than an acyclic directed graph.

Quality Attributes	
1. Accessibility	6. Efficiency
2. Adhereability	7. Effectiveness
3. Affordability	8. Empowerment
4. Authenticity	9. Safety
5. Availability	10. Trustability

Table 8.2: The list of quality attributes appearing in the second level of the ontology using the UVON method in the FI-STAR project.

APPLYING the UVON method in the FI-STAR project case, at the end of the γ phase, 10 nodes appeared below the root of the ontology tree (Table 8.2). These 10 quality attributes at the second level of the tree are parents to other child nodes; therefore, each is the unification and aggregation of other quality attributes that were originated either in the FI-STAR requirement documents or the MAST framework and reside below these 10 quality attributes. The number 10 was within the scope of practical considerations for creating an evaluation questionnaire for the FI-STAR project, but we also considered the third level of the tree to provide more details for each question in the questionnaire. Due to separation of responsibilities in the FI-STAR project, these 10 quality attributes do not represent other aspects such as the *clinical effectiveness* or *legal and ethical* ones. The number could have been larger than 10 if we had included those aspects when applying the UVON method in the project.

In the FI-STAR project, the measurement of evaluation aspects was performed through a questionnaire based on those 10 extracted aspects in the γ ontology. Two versions of the questionnaire had been created: one for the patients and one for the health professionals, where each expressed

<i>L</i>	Does the application increase <i>efficiency</i> by reducing ...					
		Strongly Agree	Agree	No Idea	Disagree	Strongly Disagree
<i>L</i>	Complexity or number of tasks?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	Number of reworks?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	Time consumed?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 8.4: Sample questionnaire output from the UVON method

Table 8.3: The mapping between MAST evaluation aspects and the final evaluation aspects for the FI-STAR project using UVON.

MAST		Final top aspect
Domains	Aspects	
Health problem and description of the application		N/A*
Safety		
	Clinical safety (patients and staff)	Safety
	Technical safety (technical reliability)	Safety
Clinical effectiveness		N/A**
	Effects on mortality	N/A**
	Effects on morbidity	N/A**
	Effects on health related quality of life (HRQL)	N/A**
	Behavioural outcomes	N/A** ,but can relate to Adhereability
	Usage of health services	N/A** ,but can relate to Adhereability

continued on the next page.

Table 8.3 – *continued from the previous page.*

MAST		Final top aspect
Domains	Aspects	
Patient perspectives	Satisfaction and acceptance	N/A ^{***}
	Understanding of information	Accessibility
	Confidence in the treatment	Trustability and Authenticity
	Ability to use the application	Accessibility
	Access and accessibility	Accessibility
	Empowerment, self-efficacy	Empowerment
Economic aspects	Amount of resources used when delivering the application and comparators	Efficiency
	Prices for each resource	Efficiency
	Related changes in use of health care	N/A [*]
	Clinical effectiveness	N/A ^{**}
	Expenditures per year	Affordability
	Revenue per year	N/A ^{**}
Organizational aspects	Process	N/A [*] , but can relate to Efficiency
	Structure	N/A [*]
	Culture	N/A [*]

continued on the next page.

Table 8.3 – *continued from the previous page.*

MAST		Final top aspect
Domains	Aspects	
Socio-cultural, ethical, and legal aspects		N/A**

* Not a quality attribute
** Not included because of the FI-STAR project definition and division of tasks
*** Had been already covered by some generic questions

the same concept in two different wordings (Note: one operation theatre case did not have patient questionnaire).

Generally and regarding practicalities of an evaluation case, it is possible to consider deeper levels of the resulting γ ontology in a given case. In the FI-STAR case, this possibility is reflected in a sample question on *efficiency* from the questionnaire (Figure 8.4), where a general question got more detailed by considering other quality attributes below the second level of the ontology. This possibility of going deeper is also depicted in Figure 8.5.

In the FI-STAR project, the quality attributes (and later the questionnaires) were delivered to each case’s stakeholders, who were asked to validate the relevancy of each quality attribute or the corresponding question regarding their case. All the cases in the FI-STAR project validated and approved their relevancy, while some asked for minor changes in the wordings of some of the questions to be clearer for the patient respondents in their case.

8.4 Discussion

ONTOLOGIES are formal and computable ways of capturing knowledge in a domain —whether local or global³¹— by specifying the domain’s key concepts (or objects) and interconnecting them by a predefined set of relations.³⁰ Formality and computability help to communicate knowledge between people or software agents, enable reuse of knowledge, make explicit declaration of the assumptions, and facilitate the analysis and study of the domain knowledge.³⁰ Inference algorithms

:what are ontologies

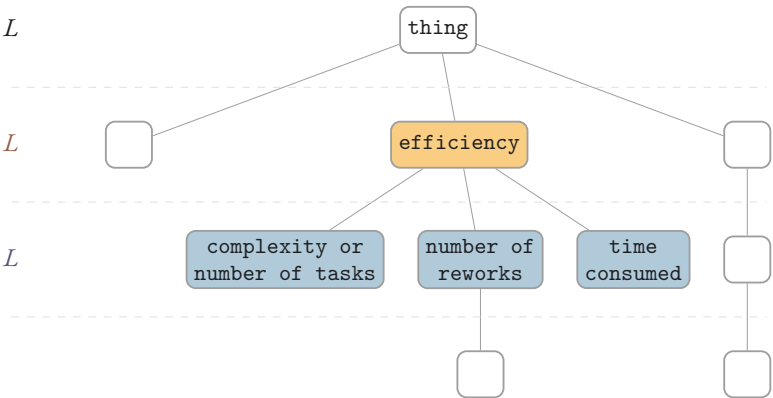


Figure 8.5: More details can be evaluated by looking at deeper nodes in the ontology structure

can infer and extract new knowledge or predict or deduce new situations by analyzing an ontology. As reflected in the above ontology description, an ontology is structured as a network (mathematically a graph). Limiting the kind of relations between the concepts might result in specific structural forms such as trees.

An ontology would be formed as a hierarchy if the relations between the concepts are limited to the *is of type* relation, where each non-leaf concept is a more generic form or super-class to its children. This hierarchy can be an *acyclic direct graph* if we allow one concept to be a sub-class of more than one other concept, and it would be a *tree* if one concept is a sub-class of only one other concept. The acyclic directed graph can be converted to a tree if we replicate the same concept-leaf in different branches. The unification that exists in the nature of a tree graph, i.e., unification of branches toward the root, is the source of unification that we want to apply for the evaluation of quality attributes in health information systems; that is why the UVON method creates this type of structure.

:unification nature of tree ontologies

Ontologies are traditionally the output of manual content curation and its associated consensus-establishment processes.³⁸ Nevertheless, automated or semi-automated methods of ontology construction might reveal considerable advantages in efficiency, repeatability, and uniformity. The UVON method described in this paper uses a semi-automatic approach toward creating tree-style ontologies for the sake of extracting

:automatic, semi-automatic, and manual ontology creation

38: Alterovitz et al. 2010

evaluation aspects.

8.4.1 *Extending the Evaluation Utilizing the Ontology*

THE ontological representation of a health information system gives a computable structure from which several indications, including evaluation aspects, can be extracted. Functions can be defined on this ontology that quantify, combine, compare, or select some of the nodes or branches. The ontology itself can be extended by assigning values to its nodes and edges, giving the possibility of further inferences. For example, if two nodes (quality attributes) are disjoint (mutually exclusive), any two children from each of them would be disjoint, respectively. If during the application of the UVON method, by mistake, one quality attribute were replicated into two disjoint branches, then this mistake can be detected and avoided automatically (replication would be disallowed between those specific nodes).

*:digging the enriched ontologies
for more indications*

As discussed in Section 8.3.2 and shown in Table 8.3, we skipped the *clinical effectiveness* and *socio-cultural, ethical, and legal* domains from the MAST framework due to the project definition. Nevertheless, the UVON method can consider those aspects when they are applicable and there are no project restrictions. Therefore, we hope to witness more inclusive applications of the UVON method in the future cases.

Also, the selection of the MAST framework was due to its common themes with the e-health applications in the FI-STAR project. We encourage application of the UVON method by considering other relevant evaluation frameworks, not necessarily MAST. The results of those applications can demonstrate the powers, weaknesses, and extension points of the FI-STAR method.

The UVON method is context-insensitive in its approach. Still, more empirical evidences with a higher degree of diversity are needed to examine what the challenges or advantages of applying the UVON method are in a more diverse range of fields beyond health information systems.

:context insensitive

8.4.2 *Limitations of the UVON Method*

THE UVON method is subject to conceptual and methodological limitations in its capacities. Probably, a prominent conceptual limitation is the fact that the method does not represent or give an account of the dynamics of the health information systems; hence, it cannot facilitate

:no consideration of dynamics

their evaluation. The relations in the UVON-constructed ontologies are restricted to the *is of type* relationship and cannot reflect how qualities or other indicators impact each other. The absence of insight about the dynamics of a health information system prevents predictive evaluations. In consequence, any emergent behavior that is not explicitly captured by requirement documents or the to-be-merged external evaluation framework is going to be ignored. From the other side, it can still be imagined that the output ontologies of the UVON method can be used as scaffolds in models that incorporate dynamics of health information systems.

THE UVON method partially relies on subjective decision-making, which can create methodological limitations and challenges. Although the main strategy in the UVON method is to minimize these subjective decisions, the existing ones can still result in creating different ontologies in different applications of the method. As a suggestion, for the sake of reaching more convergence, it is possible to think of enhancing the method with more objective lexical analytical methods. Methods of ontology construction and integration, especially those concerning class inheritance analysis,³⁵ can be valid candidates for these types of methods. *:partial subjectivity*

UVON-GENERATED ontologies are not advised for universal application. However, for a new case of evaluation, a UVON-generated ontology that was developed for similar cases can be considered as an alternative to developing a new ontology with consideration to project resource limitations. This reuse should be accomplished with due consideration to the fact that quality attributes of the same wording might indicate slightly different meanings in different cases. This case-sensitivity of meanings might result in different sub-class and super-class relations, changing the structure of the ontology and making the reuse of the unadjusted ontology problematic. *:context specificity*

THE UVON method cannot guarantee that in the output ontology each of the branches that begin from the root will reach the level of the tree (i.e., have a node at that level) where we want to base our questionnaire (or any other measurement method). Hence, a short branch might need to be extended to appear at some specific tree level where the questionnaire is based. Also, the method does not guarantee that the quality attributes in that level are all of the same degree of generality of specificity. It is also not guaranteed that the number of nodes (quality attributes) at any level *:well-formedness is not guaranteed*

matches the practicalities of evaluation; there can be too few or too many. For example, in the FI-STAR case, the number of quality attributes in the target level (level 2) had to match with the appropriate maximum number of questions that could be put in a questionnaire; fortunately, it was within the boundaries.

It is also possible, at least in theory, that all quality attributes end up being a direct child of the root *thing* node. The resultant dwarf and horizontally inflated ontology structure does not unify any of the child quality attributes; hence, the method output would be useless. The methodological limitations can result in the need for manual adjustments, such as adding extra nodes between some parent-child nodes. Of course, the manual adjustments can add more subjectivity into the formation of the ontologies.

THE UVON method permits integrating evaluation aspects from other evaluation frameworks. Still, it does not guarantee that the result will include all features of the integrated evaluation framework. Still, this integration involves the suggested evaluation aspects of those evaluation frameworks. If a framework dynamically changes its suggested evaluation aspects, for example, based on the evaluation case specifications, the UVON does not follow that dynamic feature. Also, the straightforward wordings for an evaluation aspect in an evaluation framework might be obscured by going through the integration process in the UVON method, being replaced by more generic terms.

:is integration always better?

8.5 Conclusion

THE unifying nature of ontologies, when they are in tree form, can be used to create a common ground of evaluation for heterogeneous health technologies. Ontologies can be originated from requirement and value-case documents, i.e., internal; they can be extracted from available external evaluation frameworks, i.e., external; or they can be originated from a mix of both internal and external sources. The UVON method introduced in this paper was able to create a common ground for evaluation by creating an ontology from requirement and value-case documents of the seven trial projects in the FI-STAR project and extend that ontology by mixing elements from the MAST evaluation framework. The UVON method can be used in other, similar cases to create ontologies for evaluation and to mix them with elements from other evaluation

frameworks.

The UVON method stands in contrast with other methods that do not consider case-specific internal requirements or cannot be easily extended to include other evaluation frameworks. The ontological structure of evaluation aspects created by the UVON method offers the possibility of further investigations for other indications related to evaluation of the subject systems.

The final result of applying the UVON method in the FI-STAR project resulted in 10 evaluation aspects to be chosen for measurement. This set of evaluation aspects can grow adaptively to project changes, be repeated in similar cases, and be a starting point for future evaluations in similar projects. By applying the UVON method in more cases, a possible stable result can be suggested for the set of generic evaluation aspects that are usable in evaluation cases similar to FI-STAR.

8.6 *Acknowledgment*

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Regarding the contributions, SE drafted the paper, incorporated contributions from other authors into the paper, contributed to the design of the study, developed the proposed model and method, processed data for β and γ phases of the proposed method, and contributed to the proposed method final result. PA contributed to the design of the study, contributed to the proposed method final result, supervised the research process, and reviewed and commented on the paper. TL contributed to the design of the study, supervised the research process, and reviewed and commented on the paper. SF collected data for the α phase of the proposed method and reviewed and commented on the paper. JB contributed to the design of the study, supervised the research process, and reviewed the paper.

8.7 *Conflict of Interests*

None declared.

Summary Points

What was already known on the topic? * Evaluation of health information systems is challenging and prone-to-fail in delivering the right insight. * Many of evaluation methods for health information systems consider evaluating the impact on health settings and not just the impact at the clinical level. * Evaluation frameworks for health information systems usually offer static and non-case-specific evaluation aspects.

WHAT THIS STUDY ADDED TO OUR KNOWLEDGE?

- It is possible to create a unified set of evaluation aspects by using ontology construction method, overcoming the challenge of heterogeneity of health information systems.
- It is possible to create a dynamic and case-specific evaluation framework for a health information system by using ontology construction method instead of applying fixed evaluation aspects.

[Original Paper](#)

Evaluating Health Information Systems Using Ontologies

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Abstract

Background: There are several frameworks that attempt to address the challenges of evaluation of health information systems by offering models, methods, and guidelines about what to evaluate, how to evaluate, and how to report the evaluation results. Model-based evaluation frameworks usually suggest universally applicable evaluation aspects but do not consider case-specific aspects. On the other hand, evaluation frameworks that are case specific, by eliciting user requirements, limit their output to the evaluation aspects suggested by the users in the early phases of system development. In addition, these case-specific approaches extract different sets of evaluation aspects from each case, making it challenging to collectively compare, unify, or aggregate the evaluation of a set of heterogeneous health information systems.

Objectives: The aim of this paper is to find a method capable of suggesting evaluation aspects for a set of one or more health information systems—whether similar or heterogeneous—by organizing, unifying, and aggregating the quality attributes extracted from those systems and from an external evaluation framework.

Methods: On the basis of the available literature in semantic networks and ontologies, a method (called Unified eValuation using Ontology, UVON) was developed that can organize, unify, and aggregate the quality attributes of several health information systems into a tree-style ontology structure. The method was extended to integrate its generated ontology with the evaluation aspects suggested by model-based evaluation frameworks. An approach was developed to extract evaluation aspects from the ontology that also considers evaluation case practicalities such as the maximum number of evaluation aspects to be measured or their required degree of specificity. The method was applied and tested in Future Internet Social and Technological Alignment Research (FI-STAR), a project of 7 cloud-based eHealth applications that were developed and deployed across European Union countries.

Results: The relevance of the evaluation aspects created by the UVON method for the FI-STAR project was validated by the corresponding stakeholders of each case. These evaluation aspects were extracted from a UVON-generated ontology structure that reflects both the internally declared required quality attributes in the 7 eHealth applications of the FI-STAR project and the evaluation aspects recommended by the Model for Assessment of Telemedicine applications (MAST) evaluation framework. The extracted evaluation aspects were used to create questionnaires (for the corresponding patients and health professionals) to evaluate each individual case and the whole of the FI-STAR project.

Conclusions: The UVON method can provide a relevant set of evaluation aspects for a heterogeneous set of health information systems by organizing, unifying, and aggregating the quality attributes through ontological structures. Those quality attributes can be either suggested by evaluation models or elicited from the stakeholders of those systems in the form of system requirements. The method continues to be systematic, context sensitive, and relevant across a heterogeneous set of health information systems.

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Figure 8.1: JMIR 2016: Evaluating Health Information Systems Using Ontologies

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Most Influential Qualities in Creating Satisfaction Among the Users of Health Information Systems: Study in Seven European Union Countries

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Abstract

Background Several models suggest how the qualities of a product or service influence user satisfaction. Models, such as the Customer Satisfaction Index (CSI), Technology Acceptance Model (TAM), and Delone and McLean Information Systems Success (D&M IS), demonstrate those relations and have been used in the context of health information systems.

Objectives This study aimed to investigate which qualities foster greater satisfaction among patient and professional users. In addition, we are interested in knowing to what extent improvement in those qualities can explain user satisfaction and if this makes user satisfaction a proxy indicator of those qualities.

Methods The Unified eValuation using ONtology (UVON) method was used to construct an ontology of the required qualities for 7 electronic health (eHealth) apps being developed in the Future Internet Social and Technological Align-

ment Research (FI-STAR) project, a European Union (EU) project in eHealth. The eHealth apps were deployed across 7 EU countries. The ontology included and unified the required qualities of those systems together with the aspects suggested by the Model for ASsessment of Telemedicine applications (MAST) evaluation framework. Moreover, 2 similar questionnaires for 87 patient users and 31 health professional users were elicited from the ontology. In the questionnaires, user was asked if the system has improved the specified qualities and if the user was satisfied with the system. The results were analyzed using Kendall correlation coefficients matrices, incorporating the quality and satisfaction aspects. For the next step, two partial least squares structural equation modelling (PLS-SEM) path models were developed using the quality and satisfaction measure variables and the latent construct variables that were suggested by the UVON method.

Results Most of the quality aspects grouped by the UVON method are highly correlated. Strong correlations in each group suggest that the grouped qualities can be measures that reflect a latent quality construct. The PLS-SEM path analysis for the patients reveals that the effectiveness, safety, and efficiency of treatment provided by the system are the most influential qualities in achieving and predicting user satisfaction. For the professional users, effectiveness and affordability are the most influential. The parameters of the PLS-SEM that are calculated allow for the measurement of a user satisfaction index similar to CSI for similar health information systems.

Conclusions For both patients and professionals, the effectiveness of systems highly contributes to their satisfaction. Patients care about improvements in safety and efficiency, whereas professionals care about improvements in the affordability of treatments with health information systems. User satisfaction is reflected more in the users' evaluation of system output and fulfillment of expectations but slightly less in how far the system is from ideal. Investigating sat-

isfaction scores can be a simple and fast way to infer if the system has improved the abovementioned qualities in treatment and care.

Keywords

Health Information Systems, Telemedicine, Evaluation Studies as Topic, Consumer Behavior, Treatment Outcome, Safety, Efficiency, Health Care Costs, Ontology Engineering, Equation Models

:models to explain causal relations between ultimate indicators

9.1 Introduction

THE normative evaluation of health information systems is articulated through a frequently used set of keywords such as *acceptance* or *adoption*,^{1,2} *success*,³ and *satisfaction*^{4,5}. Each of these keywords reminds us how a health information system inherits traits from its conceptual ancestors, that is, the information system, technology, and product. For an overall evaluation of these systems, one might measure how well these information systems succeed,^{6,7} how these technologies are accepted by users,^{8,9} or how the customers of these systems, patients or professionals, are satisfied with these products.¹⁰ Below this layer of top indicators, there exist sets of constructs and relationships that cause success, acceptance, or satisfaction. Researchers have tried to capture and demonstrate through the models how success,^{6,10} acceptance,⁹ or satisfaction^{11–13} are created by constructs such as perceived quality, perceived expectation, ease of use, and other variables. Some of these models have largely been employed in diverse contexts.¹⁴ There are also models, whether novel or customized from the mainstream, that are specific to a smaller context such as health information systems.^{15–17}

THE CSI model family places the *satisfaction* construct at the core of their path structures. There, the satisfaction construct is affected by leading indicators such as perceived quality. At the same time, it impacts lagging indicators such as user loyalty. There are at least three versions of CSI widely being used. The original CSI model was introduced in Sweden.¹¹ The American Customer Satisfaction Index (ACSI) improved

- 1: Fitterer et al. 2010
- 2: Li et al. 2013
- 3: Fritz et al. 2015
- 4: Ammenwerth et al. 2003
- 5: Mair et al. 2000
- 6: DeLone et al. 1992
- 7: Heeks 2006
- 8: Holden et al. 2010
- 9: Venkatesh et al. 2003
- 10: Cronin et al. 2000
- 11: Fornell 1992
- 12: Fornell et al. 1996
- 13: Eklöf et al. 2002
- 14: Urbach et al. 2009
- 15: Aragon et al. 2003
- 16: Karimi et al. 2015
- 17: Hadji et al. 2016

the Swedish version,¹² and then the European Customer Satisfaction Index (ECSI) enhanced the American version.¹⁸ The ECSI model consists of 9 latent construct variables,¹⁸ which are measured by a series of measure or manifest variables. Historically, CSI models have been used at macro levels where the satisfaction of customers at the national level or the level of an enterprise was the matter of concern. The wording of CSI models, such as the *customer* term, and the inclusion of some constructs, like *loyalty*, suggest that measuring user satisfaction at the micro level, that is, the product level, was not their main target. However, the manifestation of the satisfaction concept in the CSI models through its 3 manifest variables¹⁸ is versatile enough to measure satisfaction at both micro or macro levels with the same wording. CSI models introduce a way of measuring satisfaction scores through adding the weighted scores of those 3 variables, which inspires similar approaches in various disciplines. In comparison with using the CSI models for health information systems, one might consider the patient satisfaction models¹⁹ that share a set of common constructs and relations with the CSI models, but do not necessarily embed the same structures or components.

18: Bayol et al. 2000

19: Jackson et al. 2001

THE D&M IS model, a prevalent model for analysing the success of information systems, sets out the relationship between user satisfaction and quality dimensions.^{6,20} In this model, 3 categories of qualities, information, system, and service contribute to user satisfaction. There are 2 other constructs, *net benefits* and *intention to use*, that are in a bidirectional impact relationship with *user satisfaction*.²⁰ Several studies have validated the causal relationships between the constructs in the D&M IS model.²¹ In addition, there exists a long list of validated measures for each of the constructs.²² The D&M IS model has broadly been used in the health information system context.²³ Furthermore, it has also been extended and customized to be more specific for this context, such as in the Human, Organization, and Technology Fit (HOT-fit) model,²⁴ but the extension has been directed more toward a wider perspective of organization and technology. Although some studies have incorporated²⁵ or prioritized²⁶ more specific qualities, further investigation is needed to be more specific about the impacting qualities and their degree of importance.

20: DeLone et al. 2003

21: Urbach et al. 2012

22: Petter et al. 2008

23: Yu et al. 2009

24: Yusof et al. 2006

25: Aggelidis et al. 2012

26: Kimiafar et al. 2014

TECHNOLOGY acceptance models, such as TAM as well as the Unified Theory of Acceptance and Use of Technology (UTAUT), which

are supported by a great many of studies,^{8,9} placed the *acceptance* of a system or technology at the core of relationships. These models have been applied in health information system studies, although they have reported the significance of some of relationships differently.⁸ The user acceptance of a health information system can be a prelude to or reflection of their satisfaction in using that system, but acceptance is not the same as satisfaction. Some researchers have considered *acceptance*, that is the behavioral intention to use in TAM, an equivalent for *satisfaction*,²⁷ but the *intention to use* is a different construct from *satisfaction* in a well-studied model like D&M IS.

Contextualizing TAM by adding variables has been a common practice.^{8,28,29} Indeed, contextualizing TAM for health information technology has led to the introduction of some frequently employed variables, such as *fit*.³⁰ However, there is a shortage of studies applying a systematic approach, such as *belief elicitation*,³¹ when introducing a new variable.⁸

FOR the CSI, D&M IS, and TAM, the set of relationships between their proposed constructs have been already examined in various contexts.^{8,13,14} Nevertheless, for a specific context such as health information systems, one might seek to develop new models, probably inspired by those that are well-established, to expand a construct into more detailed constructs or find manifest variables more relevant to a case. For example, the constructs that represent the qualities of a system are generalized in those models or their variations as perceived quality;¹³ system, service or information quality;²⁰ and output quality.⁸ However, none of those models represents a specific quality, such as safety, as a standalone construct.

In addition, finding a systematic approach to define manifests for construct variables, as mentioned before, is another direction for extending a model.⁸ Many of the evaluation frameworks for health information systems suggest the qualities to evaluate,³² arranged as categories or domains. These frameworks implicitly suggest constructs and the manifests to each construct. Simultaneously, the end users of health information systems are another source for eliciting the qualities and their groupings.³³

IN the forthcoming sections, we put forth a list of qualities that create and predict user satisfaction with health information systems. The qualities are embedded within a path model that demonstrates their relationships with user satisfaction. This study's methods and materials are discussed in

27: Ives et al. 1983

28: Venkatesh 2000

29: Phichitchaisopa et al. 2013

30: Ammenwerth et al. 2006

31: Francis et al. 2004

32: Eslami Andargoli et al. 2017

33: Eivazzadeh et al. 2016

Section 9.2. The qualities elicited from the FI-STAR project by applying the UVON method are reported in Section 9.3, an exploratory result is demonstrated in Section 9.3.1, and an estimated model is presented in Section 9.3.2. The EU-wide empirical data collected through the FI-STAR project, detailed in Sections 9.A and 9.2, is used to calculate and validate the model in Section 9.3.2. The results of exploration and model calculations are discussed in Sections 9.4.1 and 9.4.2. Subsequently, based on the model, the relative importance of qualities in creating and predicting user satisfaction is discussed in Section 9.4.3. In the section Section 9.4.4, weightings are suggested for the calculation of a satisfaction index for health information systems. Finally, we examine the limits and extensions to our approach and suggested model in Section 9.4.5.

9.2 *Methods and Materials*

THE empirical data for this study has been collected from the FI-STAR project, an EU eHealth project with 7 subprojects across the EU.³⁴ A convenience sampling approach was used for the recruitment of the participants. Each eHealth app was deployed in a hospital or health facility site and the users in the site, patients or health professionals, were asked about their assessment of the impact of that specific solution on treatment. Participation in the trials, and therefore the survey, was voluntary with no mentioned preconditions. There was no constraint on the type of eHealth project being developed provided that they follow the FI-STAR requirements, especially using the Future Internet WARE (FIWARE) infrastructure. However, most of the subprojects could be categorized as telehealth apps. A summary of all subprojects can be found in Section 9.A.

:FI-STAR, the empirical data source

34: Publications Office of the European Union 2016

WE applied the UVON method³⁵ to the FI-STAR requirement documents together with the evaluation aspects from the MAST framework.³⁵ The quality aspects appearing in the result of the UVON method are supposed to be provided by the eHealth apps developed in the FI-STAR project. For each quality appeared in the UVON's output, a question was formulated according to that specific quality in the treatment. The questions were categorized according to the resulting domains in the UVON's output. The answer alternatives to the questions were formed as a 5-point Likert rating scale with unweighted scores. There were 20 qualities alongside the 3 user satisfaction questions from ECSI¹⁸ that were

35: Kidholm et al. 2012

converted to two questionnaires. One questionnaire was customized for the patients and the other one for the health professionals. The content of the questionnaires can be found in Sections 9.B and 9.C. Responses to the questionnaires by 87 patients and 31 health professionals, physicians or nurses, were used for the models suggested in this study.

IN 2 steps, we arrived at a model based on the empirical data from the answers to the questionnaires. The calculations were done using the R language, version 3.4.0.³⁶ The bootstrapped significance calculation was performed in SmartPLS software version 3.2.7 (SmartPLS GmbH).³⁷

:steps of analysis

36: R Core Team 2017

37: Ringle et al. 2015

In the first step, a matrix of Kendall correlation τ coefficients for each of the patient and professional questionnaires was formed. The results are presented in Figures 9.2 and 9.3. Moreover, we used Cronbach's α test to measure the consistency of the results in the UVON-suggested families of qualities as hints for finding constructs in the later steps. The results of the Cronbach's α test are presented in Table 9.5.

IN the second step, we created a PLS-SEM path model. For each set of the qualities that have already been grouped by the UVON method and show a high degree of correlation, a latent construct variable was considered. These latent variables are not directly measurable but manifest themselves through quality and satisfaction variables. If a quality corresponds only with a single question in the questionnaire, one latent proxy variable was considered. Consequently, it would be possible to add more measure variables to the same latent variable in future studies. The PLS-SEM analysis was performed using the *matrixpls* library in R, version 1.0.³⁸ The sample size adequacy calculations were performed using G*Power version 3.1, a program for statistical power analysis for a variety of statistical tests.³⁹

38: Rönkkö 2017

39: Faul et al. 2009

THE result of PLS-SEM should be interpreted in the context of the questionnaire. Accordingly, as discussed in Section 9.3.2, negative coefficients were considered noninformative and were excluded from the final results. The validity of the result was demonstrated through a toolbox of significance, discrimination analysis, internal consistency reliability, and convergence validity. The calculation of significance indicators was performed applying the bootstrapping approach using SmartPLS software.³⁷ Whenever applicable, the noninformative nature of negative coefficients was considered during the validity and fitness calculations.⁴⁰

:filtering and validation

40: Kock 2015

9.3 Results

APPLYING the methods mentioned in Section 9.2 produced the following results; a more detailed discussion can be found in Section 9.4.

THE result of applying the UVON method on the FI-STAR project was a tree-style ontology of qualities, of which the top-level qualities are listed in Table 9.2.³³ The questionnaires articulate those qualities and their more specific subqualities. Table 9.2 is just an overview of the qualities; details of the questions that were created for each quality can be found in Sections 9.B and 9.C. *:UVON result*

Descriptive statistics of the variables in the patient and professional questionnaires, including mean, standard deviation, and median, are shown in Tables 9.3 and 9.4.

9.3.1 Correlation Patterns

As can be seen in Figures 9.2 and 9.3, a spectrum of weak to strong correlation coefficients appeared in the *Corrgram* diagrams⁴¹ for the patient and professional questionnaire. The blank cells are the results that were not statistically important ($p > 0.05$). The results of the Cronbach's α test can be found in Table 9.5. *:inter-correlations and what they point out*

9.3.2 The PLS-SEM models

THE 2 PLS-SEM models and their loadings and coefficient values are depicted in Figures 9.4 and 9.5. As is common with path models, latent variables are depicted as ovals, whereas manifests are shown as boxes. We considered all the measure variables as reflective, that is they do not construct their respected latent variables, but they measure or manifest them. The number label on the edge between a manifest and a latent variable is the loading, and the number label on the edge between two latent variables is the coefficient.

41: Friendly 2002

THE most contributing and predictive qualities regarding satisfaction are reported in Table 9.6 by specifying the coefficients of relationships between qualities and the satisfaction construct. For the patients, the coefficients of effectiveness, safety, and efficiency qualities were higher than

Qualities
1. Accessibility: if the app is accessible to different users.
2. Adherence: if the patients adhere more to treatment because of the app.
3. Affordability: if the treatment became more affordable for the patient or health care system because of the app.
4. Authenticity: if the information provided by the app is authentic and correct (combined with safety).
5. Availability: if the service provided by the app is available by demand.
6. Efficiency: if the treatment is more efficient because the app was used.
7. Effectiveness: if the treatment process is more effective because the app was used (except for clinical effectiveness).
8. Empowerment: if the app empowers the patient or health professional to know more about their conditions or perform their tasks better.
9. Safety: if the app itself is safe, or makes the treatment process safer.
10. Trustability: if the app improves the trust of the patients in treatment.

Table 9.2: The quality attributes resulting from applying the UVON method to FI-STAR requirement documents.

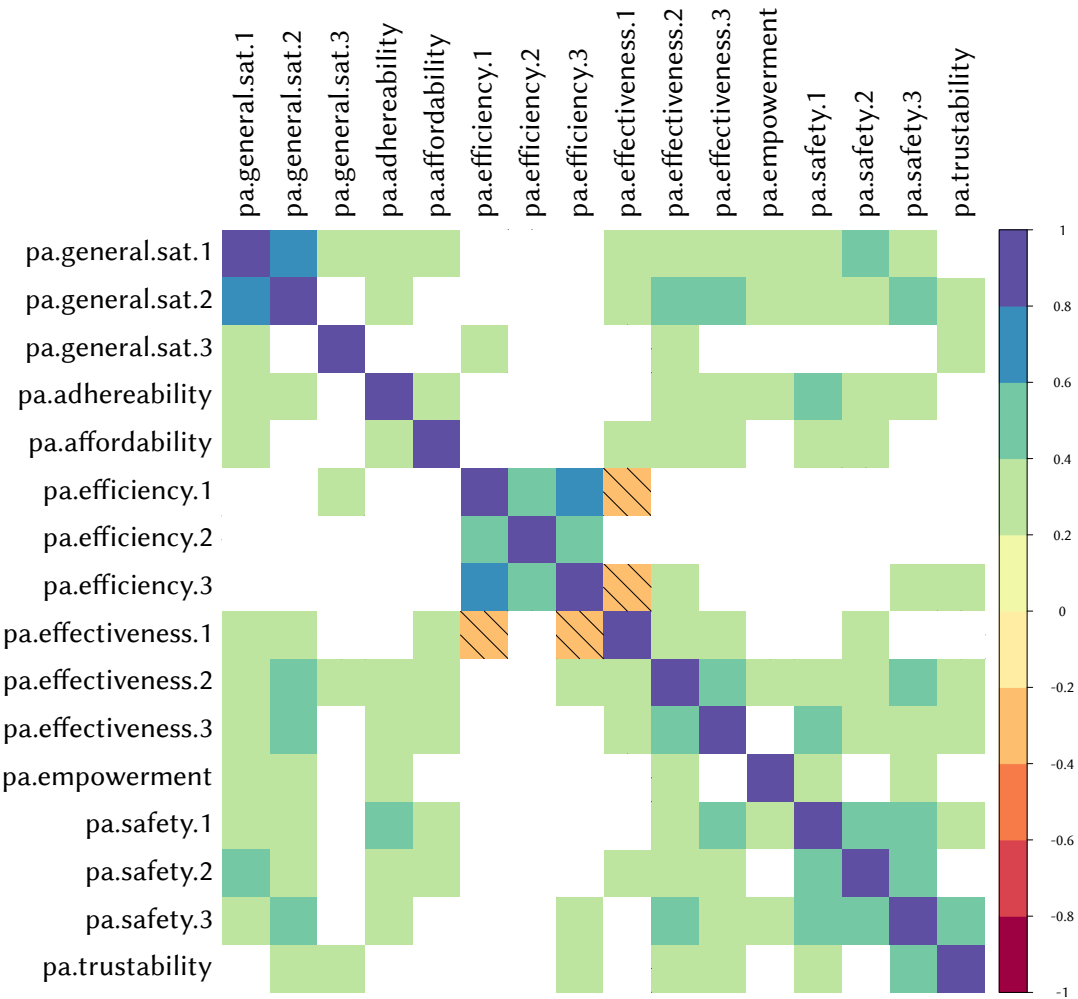


Figure 9.2: Correlation matrix for the patient questionnaire results across all cases. For the details of each variable, refer to the corresponding question in Section 9.B. Insignificant ($p > 0.05$) results are left blank. Negative results are marked with leftward- slanting lines. Note that the qualities grouped by the UVON method usually show higher correlations together.

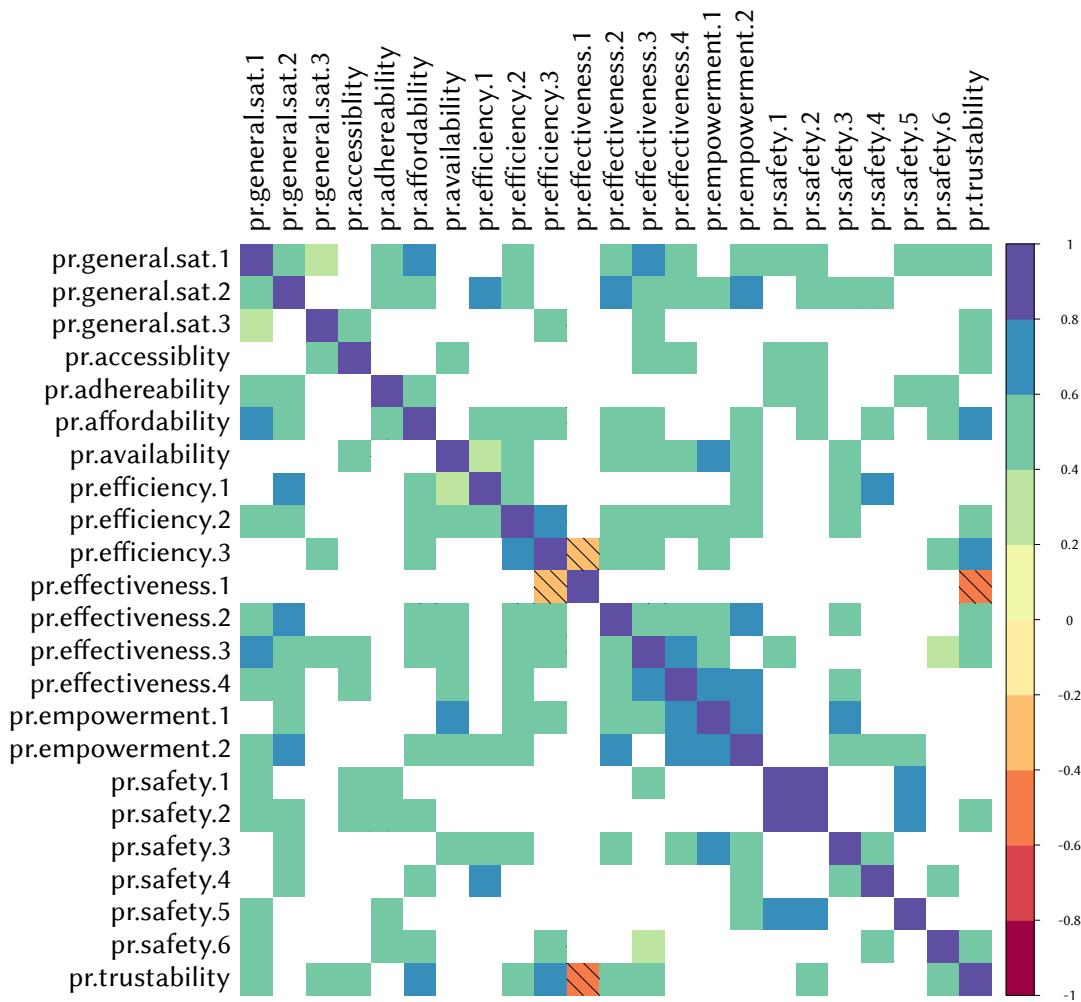


Figure 9.3: Correlation matrix for the professional questionnaire results across all cases. For the details of each variable, refer to the corresponding question in Section 9.B. Insignificant ($p > 0.05$) results are left blank. Note that the qualities grouped by the UVON method usually show higher correlations together.

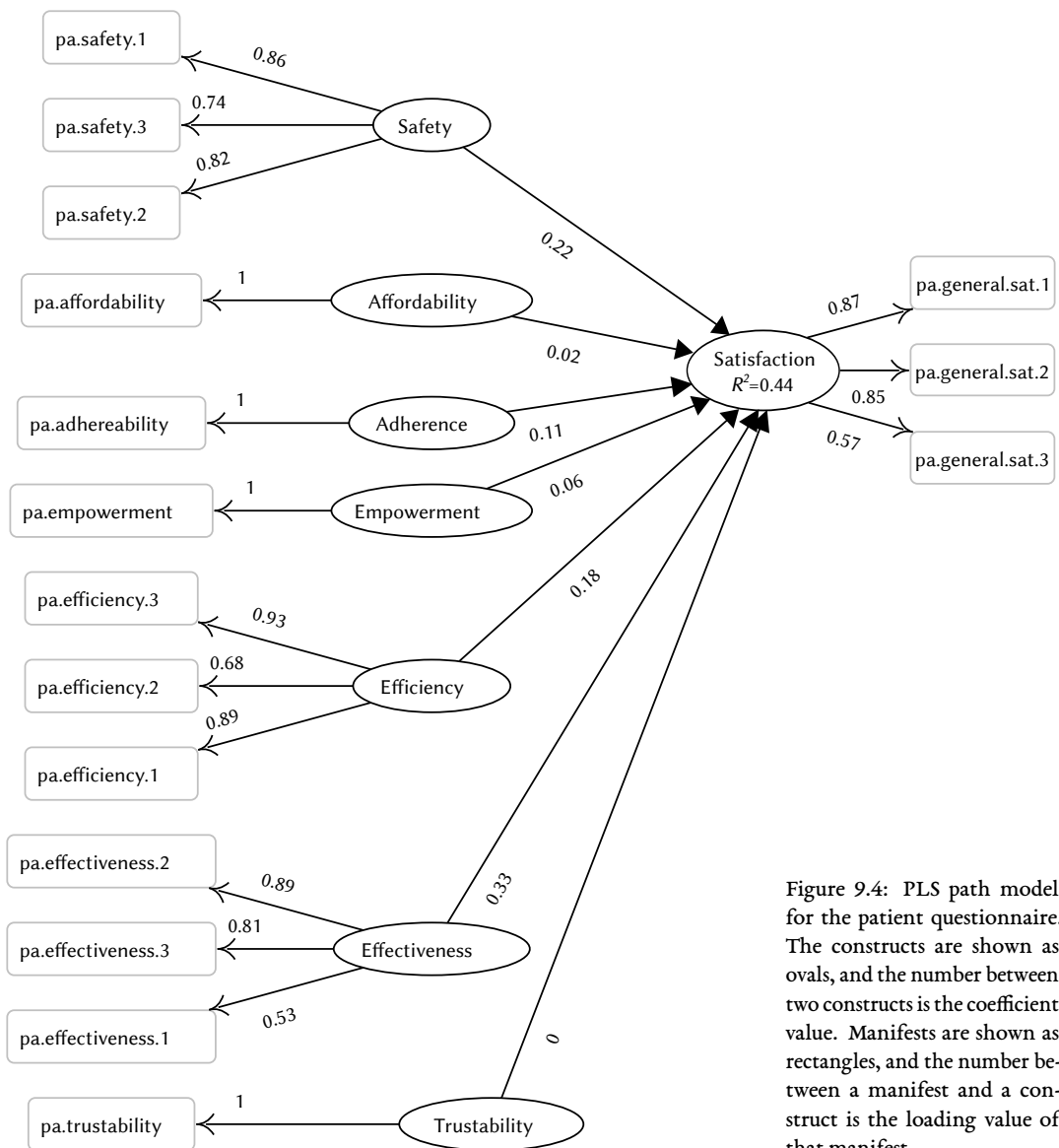


Figure 9.4: PLS path model for the patient questionnaire. The constructs are shown as ovals, and the number between two constructs is the coefficient value. Manifests are shown as rectangles, and the number between a manifest and a construct is the loading value of that manifest.

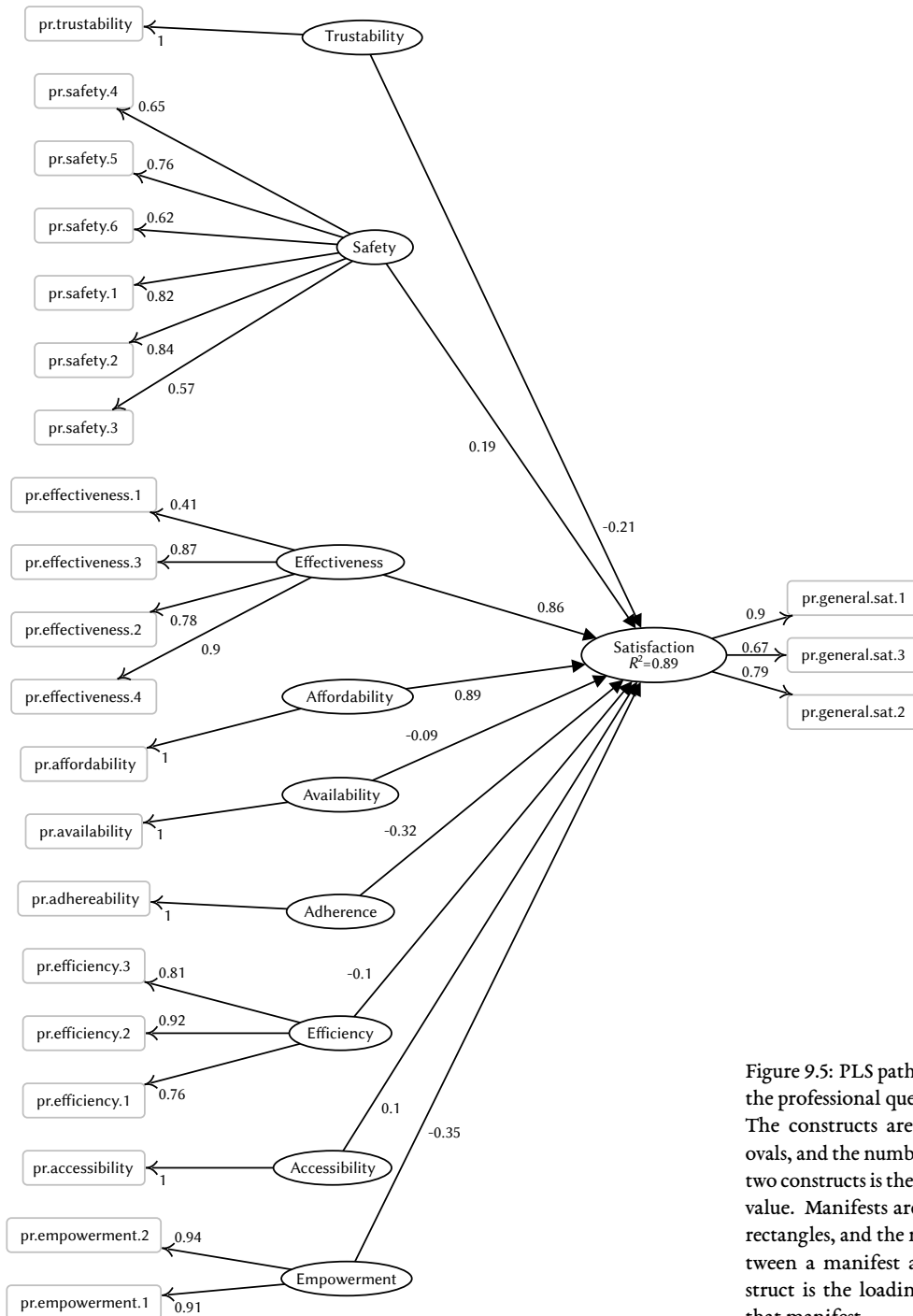


Figure 9.5: PLS path model for the professional questionnaire. The constructs are shown as ovals, and the number between two constructs is the coefficient value. Manifests are shown as rectangles, and the number between a manifest and a construct is the loading value of that manifest.

Quality	Mean (SD)	Median
pa.adhereability	4.35 (0.73)	4.00
pa.affordability	4.1 (1.05)	4.00
pa.effectiveness.1	3.76 (0.94)	4.00
pa.effectiveness.2	4.28 (0.94)	5.00
pa.effectiveness.3	4.57 (0.77)	5.00
pa.efficiency.1	3.82 (0.88)	4.00
pa.efficiency.2	3.47 (0.9)	3.00
pa.efficiency.3	3.78 (0.97)	4.00
pa.empowerment	4.33 (0.9)	5.00
pa.general.sat.1	4.51 (0.79)	5.00
pa.general.sat.2	4.46 (0.73)	5.00
pa.general.sat.3	4.01 (1)	4.00
pa.safety.1	4.76 (0.46)	5.00
pa.safety.2	4.58 (0.64)	5.00
pa.safety.3	4.5 (0.86)	5.00
pa.trustability	4.62 (0.72)	5.00

Table 9.3: Descriptive statistics of the variables in the patient questionnaire.

the average (0.13) of all coefficients. Like the professional, coefficients of the affordability and effectiveness qualities were higher than the average (.51) of all coefficients.

The relationship of each measure variable in the path model with its construct is associated with weights. The standardized weights for the satisfaction construct measure variables are required for calculating the *user satisfaction index* and can be found in Table 9.7.

THE *P* value results of calculating the significance of quality to success relationships using the bootstrapping approach are shown in Table 9.8. The *P* values below 0.05 are marked with an asterisk. Regarding discriminant analysis, the results of the heterotrait-monotrait (HTMT) ratio are demonstrated in Table 9.9. HTMT being below 1.0, preferably 0.9, satisfies the discriminatory criterion.⁴²

:validation results

42: Henseler et al. 2015

The effect sizes of the samples were enough to show significant results for the highest loading constructs, as shown in Table 9.6. Details of the effect sizes and their associated power, by recalculating the PLS-SEM and focusing on significant relations, are shown in Table 9.11 in Section 9.D.

For internal consistency reliability composite reliability (CR) values and for convergence validity, average variance extracted (AVE) values

Quality	Mean (SD)	Median
pr.accessibility	3.96 (0.88)	4
pr.adhereability	3.91 (0.9)	4
pr.affordability	4.22 (0.8)	4
pr.availability	3.61 (0.99)	4
pr.effectiveness.1	3.39 (0.78)	4
pr.effectiveness.2	4.04 (0.77)	4
pr.effectiveness.3	4.26 (0.81)	4
pr.effectiveness.4	4.26 (0.81)	4
pr.efficiency.1	3.04 (1.02)	3
pr.efficiency.2	3.65 (0.93)	4
pr.efficiency.3	3.91 (1.12)	4
pr.empowerment.1	4.39 (0.58)	4
pr.empowerment.2	4.3 (0.47)	4
pr.general.sat.1	3.87 (1.1)	4
pr.general.sat.2	3.87 (0.97)	4
pr.general.sat.3	3.52 (0.9)	4
pr.safety.1	4.61 (0.58)	5
pr.safety.2	4.57 (0.59)	5
pr.safety.3	4 (0.67)	4
pr.safety.4	3.78 (0.8)	4
pr.safety.5	4.26 (0.69)	4
pr.safety.6	3.96 (0.82)	4
pr.trustability	4.22 (0.74)	4

Table 9.4: Descriptive statistics of the variables in the professional questionnaire.

	Quality Group	Cronbach's α
Patients	pa.general.sat.X	.63
	pa.efficiency.X	.80
	pa.effectiveness.X	.63
	pa.safety.X	.67
Professionals	pr.general.sat.X	.70
	pr.efficiency.X	.77
	pr.effectiveness.X	.75
	pr.empowerment.X	.82
	pr.safety.X	.79

Table 9.5: Cronbach's α test results for the quality groups. Although a score over .7 is usually considered the desired cut-off criterion, the CR values in Table 9.10 can still better determine reliability.

Quality Construct	Coefficient	
	Patient	Professional
Effectiveness	.33	.86
Safety	.22	.19
Affordability	.02	.89
Efficiency	.18	
Adherence	.11	
Empowerment	.06	
Trustability	.00	
Accessibility		.10

Table 9.6: The coefficients of the qualities to Satisfaction relationships in the PLS-SEM path model show which qualities contribute more to satisfaction. Negative values were left blank as being non-informative (see Section 9.4.2). For the conclusion, one should consider the significance, as shown in Table 9.8.

		Standardized Weight
Patient Satisfaction	pa.general.sat.1	.36
	pa.general.sat.2	.38
	pa.general.sat.3	.25
Professional Satisfaction	pr.general.sat.1	.40
	pr.general.sat.2	.32
	pr.general.sat.3	.28

Table 9.7: Standard weights for calculating the satisfaction index, based on the manifest variable loadings for the Satisfaction constructs in the patient and professional path models.

were calculated for each construct, as depicted in Table 9.10. The minimum CR should preferably be above 0.7.⁴³ The minimum AVE should preferably be above 0.5.⁴⁴

43: Henseler et al. 2012

44: Chin 1998

Antecedent to Satisfaction	<i>p</i> Value	
	Patient	Professional
Adherence	.16	.13
Affordability	.38	.04*
Effectiveness	.01*	.01*
Efficiency	.03*	.37
Empowerment	.25	.20
Safety	.04*	.38
Trustability	.48	.30
Accessibility		.41
Availability		.418

Table 9.8: Significance of the quality to Success relationships by calculating the *P* values of the relationships between the qualities and the Satisfaction construct. The *p* values less than .05 are marked with an asterisk.

Construct Pairs (A vs. B)	HTMT	
	Patient	Professional
Efficiency → Satisfaction	0.21	0.84
Effectiveness → Satisfaction	0.79	1.07
Safety → Satisfaction	0.69	0.91
Effectiveness → Efficiency	0.04	0.68
Safety → Efficiency	0.09	0.62
Safety → Effectiveness	0.75	0.68
Empowerment → Satisfaction		0.69
Empowerment → Efficiency		0.76
Empowerment → Effectiveness		0.97
Safety → Empowerment		0.63

Table 9.9: The discriminant validity analysis shows if the manifests of a construct in the patient or professional PLS-SEM models has the strongest relationship with that construct compared with another construct. HTMT ratio results below 1.0, preferably 0.9, satisfy the discriminatory criterion.

Construct	Patient		Professional	
	CR	AVE	CR	AVE
Satisfaction	0.82	0.60	0.83	0.63
Adherence	1.00	1.00	1.00	1.00
Affordability	1.00	1.00	1.00	1.00
Efficiency	0.88	0.71	0.87	0.70
Effectiveness	0.80	0.57	0.84	0.58
Empowerment	1.00	1.00	0.92	0.85
Safety	0.85	0.66	0.86	0.51
Trustability	1.00	1.00	1.00	1.00
Accessibility			1.00	1.00
Availability			1.00	1.00

Table 9.10: The result of internal consistency reliability of the manifest variables by measuring CR and their convergence by calculating AVE, grouped by constructs. A CR value above 0.7 and an AVE value above 0.5 are preferred.

9.4 Discussion

THIS study advances and prioritizes the qualities in health information systems that determine and predict user satisfaction, both for patients and health professionals. As a secondary outcome, it also suggests weightings for calculating the *satisfaction index*. The outcomes of the study exhibit the effectiveness of the UVON method in proposing quality constructs that can be applied to a path analysis. Conclusions from the results are achieved in 2 steps. First, the correlations give better insight about the groupings of the qualities as manifest variables of the latent constructs. Second, the path model justifies and quantifies the relationship between those grouped qualities, their latent construct variables, and the satisfaction construct.

9.4.1 The Correlations

IN the exploratory step, as shown in Figures 9.2 and 9.3, strong correlations appear between the qualities that have been already grouped into a family by the UVON method. These high correlations result from the semantic unification of qualities across branches of an ontological tree by the UVON method.³³ For example, a set of above-medium correlations exist within the efficiency, effectiveness, and safety family of qualities in the patient questionnaire results, as well as within the empowerment, effectiveness, safety, and efficiency families in the professional questionnaire results. The same is true for the satisfaction questions in both groups of questionnaires.

inter-family correlations and the latent variables

The above correlations suggest that the members of a quality or satisfaction group can be combined. Alternatively, in other words, they manifest a common latent variable. It is worth mentioning that the Kendall correlation τ is less generous than Spearman's ρ in confirming the correlations.⁴⁵ Hence, there would be more confidence in positively interpreting the correlation results and suggesting a common latent origin. The Cronbach's α results in Table 9.5 confirm the same explanation in the quality groups.

45: Gilpin 1993

Besides the possible existence of latent variables, there are 2 other corollaries to the correlations. First, the high degree of correlation between a family of qualities results in the multicollinearity problem. Multicollinearity makes ordinary regression techniques inefficient, and the interpretation of the regression coefficients challenging.⁴⁶ Two solutions

46: Farrar et al. 1967

can be taken here: choose one of the variables that show high correlation with each other by using variable selection methods, such as least absolute shrinkage and selection operator (LASSO) or apply a method that is tolerant to the problem. The PLS-SEM approach used in this study is tolerant to multi-collinearity; meanwhile, it can investigate the causality relations between some correlated quality groups.

Second, the correlation between qualities and satisfaction aspects suggests a causality relationship between quality and user satisfaction. Similarly, there are models, such as the CSI family of models^{11–13} as well as the D&M IS model,²⁰ that demonstrate a causality relationship between qualities and satisfaction in parts of their structure. We can draw on corroborations from the extensive amount of literature about those models, both to enrich our model and verify the results.

A summary of the above discussion is that we can group the qualities within a family as manifests of a latent variable, consider a causal relationship from those quality latent variables to a satisfaction latent variable, and present these groupings and relationships through a PLS-SEM model.

9.4.2 The PLS-SEM models

THE PLS-SEM path model has traditionally been used to represent causalities for the CSI series,^{11,12,47} the models related to D&M IS,^{48,49} and similar intentions.⁵⁰ This prevalence of usage gives the opportunity to reuse some of those models' parts, compare their structures, and collate their results. Other advantages of the PLS-SEM approach are the need for small sample size and the ability of handling non-normal data.⁵⁰

The 2 PLS-SEM path models in this study comply with the general pattern in CSI, D&M IS, and TAM series models in which a central construct — be it called system success, user satisfaction, customer satisfaction, or user acceptance — is influenced by system qualities. Besides the use of different constructs, each model captures a distinct level of detail for the same or similar concepts. The CSI and TAM models are more concerned about the general perception of quality, whereas D&M IS examines further details about the qualities by considering 3 separate constructs: *system quality*, *information quality*, and *service quality*. The model presented in this study is inclined to be more domain-specific by focusing on the health information system domain. The model is also more concerned with the qualities improved in the whole treatment

47: Henseler et al. 2016

48: Hsu 2008

49: Livari 2005

50: Hair et al. 2014

setting by using the health information system rather than the qualities of the system. Finally, in comparison with the previously mentioned mainstream models, the model in this study is more specific about the type of qualities and how they compare in determining and predicting user satisfaction.

BEFORE discussing the qualities with the most influence on satisfaction, model validity and the right way of interpreting the results need to be investigated. *:discriminatory validation*

Regarding internal consistency reliability, CR indicators need to be higher than 0.7,⁴³ which is well satisfied (see Table 9.10). The CR shows if the manifest variables of each construct measure the same thing. The convergent indicator AVE needs to be more than 0.5 to indicate that more than half of the variance in the measures is because the variance in the construct.⁴⁴ All the constructs in our PLS-SEM model satisfy this criterion (refer to Table 9.10).

From the discriminatory validation perspective, both patient and professional models show indications of correctly assigning the measure to construct variables. The HTMT ratio demonstrates if the assignment of measuring variables to a specific construct is better, that is more relevant, than other alternatives. All the HTMT results in both models, except one as shown in Table 9.9, satisfy the specified criterion of being less than 1. Furthermore, most of the HTMT values are less than 0.9, which confirms discriminant validity.⁴² The only pair of constructs that have a ratio value above 1 is the *effectiveness* and *satisfaction* pair for professionals. However, this unfulfilled criterion might be justified considering that, in the domain, one should segregate satisfaction and effectiveness, while effectiveness highly contributes to satisfaction. The relatively high HTMT ratio for the pair of *empowerment* and *effectiveness* can indicate that the users' empowerment to reach effectiveness is not very distinctive from the improved effectiveness.

THE interpretation of the negative coefficients that appeared in the models must be discussed. The wording in the FI-STAR questionnaires captures only the user perspective on positive relationships but not the negative ones. The information gathered from the questions is unidirectional. Therefore, one cannot interpret the negative coefficients as an indication that some qualities are inversely related to satisfaction. *:interpretation of the negative coefficients*

For example, if it is asked whether the app has increased the effective-

ness of a treatment by decreasing the number of mistakes, a responder might answer “disagree”. This answer can mean whether the user does not believe that the app has decreased the number of mistakes in the treatment; or the user might think that the app has decreased the number of mistakes, but does not contribute to the system’s effectiveness. On the other hand, it is still a possible interpretation that the app has caused more mistakes, however, we cannot separate this interpretation from the other previously mentioned valid interpretations. Therefore, we can only confirm the positive part of relationships, where quality contributes to user satisfaction.

9.4.3 *Most Influential Qualities*

As shown in Table 9.8, there are constructs whose relationships to the satisfaction construct are statistically significant. Those constructs also have considerable impact on satisfaction, as depicted in Table 9.6. Regarding satisfaction as the major contributor to success⁵¹ and the indicator of voluntary acceptance,¹⁴ we extend our discussion to cover similar studies that report on these 2 indicators.

:*effectiveness discussion*

51: Seddon et al. 1996

Within the list of qualities in Table 9.8 with a significant relationship to the satisfaction construct, the degree of *effectiveness* is considerably predictive in creating satisfaction. Both patients and professionals care considerably whether an app has increased the effectiveness of treatment and care. This result highlights the nonintuitive contrast between the effectiveness of other qualities, such as the efficiency for patients, in affecting their satisfaction. Nevertheless, there can be alternative interpretations. For example, if the apps in the FI-STAR project could significantly improve efficiency for patients, efficiency might have shown an impact as the effectiveness on satisfaction.

This result confirms the studies that consider effectiveness the major contributor or even equivalent to user satisfaction, generally, in information systems.^{14,51,52} More specifically, this study parallels the studies that reported effectiveness (sometimes expressed as usefulness) as the most, or one of the most, influential qualities for the satisfaction of patients⁵³ or health professional users^{54–56} in a variety of health information systems. Nevertheless, there exist studies that reached a different conclusion in prioritizing the most influential qualities.⁵⁷

52: Bailey et al. 1983

53: Jo et al. 2017

54: Liu et al. 2015

55: Hu et al. 1999

56: Schaper et al. 2007

It should be noted that improvements in the *effectiveness* of the treatment is not articulated identically in all those studies. For comparison,

57: Wu et al. 2007

one needs to consider this discrepancy.⁸ Some studies have used *performance*,⁵⁴ a term presumably borrowed from the D&M IS and TAM families. In addition, some studies reported similar manifest variables to effectiveness in our study — see Sections 9.B and 9.C — such as making fewer mistakes.⁵⁸

58: Kim et al. 2012

ACCORDING to our results, *affordability* has a high degree of impact on satisfaction for professionals, similar to effectiveness. The study could not generate significant results regarding the affordability to satisfaction relationship from the patient perspective, whereas this nonsignificant impact result is also negligible. An explanation might be that, in the FI-STAR setting, patients did not have to be concerned about the costs and affordability of solutions, while professionals might have a more holistic perspective. In a different setting, where patients are more concerned about treatment costs, their satisfaction might be more influenced by the improvements in affordability, showing higher significance and magnitude in the coefficient that relates affordability to satisfaction constructs.

:*affordability discussion*

Although studies report increased affordability and cost reduction in treatment can improve the satisfaction and acceptance of health information systems,^{2,59} only some of these studies quantify or compare the degree that affordability and cost reduction affect satisfaction. In addition, many studies such as ours could not report definitively how patients perceived cost-reduction quality, considering patients usually do not pay for treatment in the context of a study.^{5,60} Some studies that rely on TAM models have considered affordability, alongside other factors, as a manifest to *perceived usefulness*.^{8,61,62} These studies show a relatively high or above-average impact on professional users' satisfaction, acceptance, or intention to use.^{61,62} Our results in Table 9.6 comply with these studies. It is worth noting that some studies declared the same idea in a negative form, where being costly is considered a barrier to acceptance^{2,60,63} or success.⁷

59: Akter et al. 2011

60: Handayani et al. 2017

61: Hsiao et al. 2013

62: Steininger et al. 2014

63: Berner et al. 2005

PATIENTS showed some degree of improved satisfaction when there was an improvement in *efficiency* or *safety*. It is important to note that health information systems, as a side effect, can degrade the status of efficiency or safety in a health care setting.⁶⁴ Hence, their contribution to overall satisfaction can even be negative. However, as highlighted before, our questionnaires were not designed to differentiate between the states of negative impact and no impact.

:*efficiency discussions*

64: Boonstra et al. 2010

Considering most of the apps in the FI-STAR project could be categorized as telemedicine apps (please refer to Section 9.A), it could be predicted that efficiency, achieved by eliminating the hassle of distant travels, contributes to user satisfaction to some extent. Despite our initial expectations, the degree of impact on satisfaction, although existing, was less than the previously mentioned factors. Our expectation was based on similar studies that investigated the impact of efficiency improvements on satisfaction and acceptance: the degree of impact was recorded relatively more than our study.¹ It is also important to note that we considered a separate category for affordability and cost saving quality, whereas some studies considered cost saving a form of improving efficiency⁶⁵ or a manifest to *perceived usefulness*;⁶² therefore, other results should be compared with more attention to this detail. From the other side, some studies considered other forms of efficiency, rather than affordability, as manifests to *perceived usefulness*.^{55,66,67} Regarding the coefficients and loadings in models of the aforementioned studies, in comparison with our results, they have recorded a higher impact from efficiency on the satisfaction or acceptance of users.

65: Schweitzer et al. 2012

66: Tung et al. 2008

67: Zailani et al. 2014

:safety discussion

LOOKING at the safety questions for the patients in Section 9.B, it seems that being informed about the situation and capable of keeping the situation in check is the source of the safety to satisfaction causality. Like other qualities, safety has been categorized in various constructs in the studies, whether as a manifest to *provider performance*,⁶⁸ *perceived usefulness*,⁶² *outcome*,⁶² or *information satisfaction*.⁶²

68: Salleh et al. 2016

To the best of our knowledge, there are few studies that investigate the impact of safety brought by health information systems on the satisfaction or acceptance of the users of those systems. However, one should pay attention to this caveat that the *safety* concept might have divergent embodiments in various studies. Two of the manifest variables in our models, *pa.safety.2* and *pr.safety.3*, refer to providing correct information which is also mentioned in distinct studies, mostly as a manifest variable for the *information quality* construct.^{26,58,69} In these studies, providing the correct information influences satisfaction or acceptance relatively high or above average. Moreover, there are some studies on the systems in which their primary function is to improve safety aspects. As can be anticipated, they report a high impact from safety on the intention to use.^{70,71}

69: Pai et al. 2011

70: Wong et al. 2012

71: Peeters et al. 2012

9.4.4 *Satisfaction Index*

EACH of the satisfaction constructs in the PLS-SEM models is operationalized by 3 measure variables, embodied as 3 questions. The relationship of each of these measure variables with the latent satisfaction construct is characterized by loading and weighting values. The weighting values make it possible to calculate a weighted *satisfaction index*, both for patients and professionals. Using this index can be a makeshift way of assessing qualities inside health information systems.

The standardized weightings for the scores of the 3 measure questions of satisfaction are determined by the overall balance in the model as it is implemented by the PLS-SEM algorithm. The weightings, along with the scores of those 3 questions, make it possible to calculate the user satisfaction that is engendered by the improvement of qualities. Without the weightings, the satisfaction score represents the evaluation of a kind of unidentified trait that is relevant but not necessarily the same as a quality engendered satisfaction. A larger and more diverse sample population of respondents and apps might be needed to stabilize the weightings for a larger scope.

Collecting satisfaction scores is a common practice in health-related studies. However, to the best of our knowledge, the studies on health information systems that suggest a kind of satisfaction index with adjusted weights regarding other qualities are limited. Conversely, the studies that have calculated the parameters of TAM or D&M IS models in their contexts or have used a path model that includes user satisfaction alongside other impacted qualities, such as^{53,56,69}, implicitly suggest a kind of indexing for adoption and satisfaction aspects. Nevertheless, there are barriers to utilizing the measures suggested for the satisfaction construct. First, the extent and diversity of subjects in these studies are important factors to reuse their suggested measures and their associated weights. Second, using arbitrary measure questions or the number of items for measurement can create a burden beyond a study's resources. A sample of this case is the End User Computing Satisfaction (EUCS) measures that range from 12 to 39 items.^{52,72} Although some studies have the required resources to apply them,²⁵ using those instruments is not feasible in many other cases. Our focus on the 3 standard satisfaction measures from CSI makes it easier to implement the study and simultaneously facilitates the running of interdisciplinary comparisons and knowledge about the satisfaction of users (customers) of health information systems

:*satisfaction index*

:*other satisfaction indexes*

72: Doll et al. 2004

and other services and products.

The qualities investigated in this study can explain different amounts of satisfaction variations with $R^2 = 0.43$ for patient satisfaction and $R^2 = 0.88$ for professional satisfaction, as depicted in Figures 9.4 and 9.5). The satisfaction index can facilitate an informed guess about the qualities when the user perspectives on those qualities are missing or hard to elicit. This approach is a makeshift way to evaluate the qualities improved by a system. A practical app might be to use the satisfaction index when comparing two similar systems in similar contexts. Another app is to compare the past and present state of the same system that has undergone quality improvement, but no other system or environmental aspect has been changed. Generally, if there are similarities in context and functionalities, and there has been no drastic change or difference in qualities improved by systems, the satisfaction index can serve as a good indicator for an informed guess about those qualities.

:satisfaction index for fast
compare of qualities

9.4.5 Extensions and Limitations

THE list of most influential qualities should be read with the precaution of how the similar or even the same qualities have been articulated differently in studies.⁷³ Studies that recruit highly cited frameworks also tend to recruit similar wordings for the qualities. However, other studies practice their freedom to use the wording that best matches their case, resulting in divergent wordings for similar concepts. In our case, notably, the improvement of a treatment's *effectiveness* is largely similar to *performance* or *performance expectancy* in the studies that are based on the TAM family and consider the *performance expectancy* definition as "the degree to which an individual believes that using the system will help him or her to attain gains in job performance".⁷⁴ It is similar to what we asked about effectiveness (refer to Sections 9.B and 9.C). However, one can still find research based on TAM studies that used *performance expectancy* as a form of efficiency.²⁹ In addition, *efficiency* in our study is more or less similar to *effort expectancy* or *perceived usefulness* in the TAM series. Some other studies have used *productivity* or even *performance* instead of what we called efficiency,⁶⁸ and others considered efficiency as a manifest to *perceived usefulness*.^{8,55,66,67}

:different wordings for the
same or similar qualities

73: DeFranco et al. 2017

74: Davis 1989

Another caveat when comparing the results is that the qualities specified in our study are the qualities of the treatment or care that using FI-STAR systems might have improved, which are different from the

intrinsic qualities of those systems. Accordingly, for example, a higher speed system might increase the affordability of treatment and care in some way. What we have focused on was the affordability of care but not the speed of the system. Therefore, reports on the intrinsic system qualities that have increased user satisfaction or acceptance cannot be compared directly with our study, unless those qualities get translated to their final impact on treatment and care.

ALL the eHealth apps, being developed in the FI-STAR project, were supposed to support the required general technical specifications which includes using the FIWARE infrastructure and being based on *software to data* paradigm.⁷⁵ These requirements were not constraints on the diversity of apps, as it is indicated in Section 9.A. Nevertheless, the diversity of the apps should be considered when generalizing the results of this study. For example, if the main outcome of an app is improving the safety of treatment, users might consider both safety and effectiveness almost the same; however in other apps they can consider them as distinctive qualities. As another example, the effect of some apps on affordability of treatment can be varied in a different context, when the patients pay for the treatment. This study relies on the output of the UVON method, which extracts common qualities between a set of apps, however as it is shown in abovementioned examples, user perspectives on those common qualities could be diverse. Therefore, generalization of the results of this study should be done with bearing this caveat in mind.

75: FI-STAR Consortium
2014

THE predictive power of qualities in projecting user satisfaction can support design decision making for health information systems. When trade-offs are necessary, designers can prioritize features if they can compare their user satisfaction yield. Knowing the quality profile of each feature, one can combine that with the table of quality to satisfaction magnitudes, such as in Table 9.6, to arrive at more informed feature selection decisions.⁷⁶

76: Eivazzadeh et al. 2015

ANOTHER extension to the model of this study is to consider the qualities or system usage ramifications that impact satisfaction negatively. This needs to articulate questions to capture negative attitudes — not noninformative ones — about the impacts of systems. That kind of wording permits elicitation of constructs that are negatively related to

other constructs or new manifest variables for the current constructs that reflect the construct negatively.

A possible future extension to our PLS-SEM model is to consider relationships between quality latent variables. In the model presented in this study, no relationship has been proposed between the quality constructs, but one might try, for example, to investigate if a system that improves adherence also changes user attitudes about its contribution to effectiveness. However, considering that only recursive relationships can be used in the PLS-SEM models, we cannot investigate the circular impact between qualities and satisfaction with this technique.⁷⁷

77: Monecke et al. 2012

9.5 Conclusions

THE satisfaction of health information system users is highly influenced by certain qualities that are improved by those systems. Both patient and professional users consider improvements to the effectiveness of health care a highly important quality that makes them satisfied with the system. For patient users, safety and efficiency qualities come after effectiveness in creating satisfaction. For health professionals, better health care affordability brought by health information systems is important, much like effectiveness, in creating their satisfaction.

The PLS-SEM model presented in this study can demonstrate the above ranking of qualities in the creation of user satisfaction. Furthermore, the model suggests weightings to calculate the *satisfaction index* for health information systems. The satisfaction index can be used to compare and monitor health information systems from user satisfaction and quality improvement perspectives.

Summary Points

Study focus

- The study focuses on the qualities that contribute most to the satisfaction of the users of health information systems across EU.

Key messages

- Effectiveness, safety, and efficiency are the most important qualities to create satisfaction for the patient users across the EU.
- Effectiveness and affordability are the most important qualities for creating satisfaction for health care professional users, across the EU.
- The satisfaction index appears to be a way of comparing quality improvements across systems

Strengths

- More specific qualities have been detailed for the context of health information systems that contribute to user satisfaction.
- The satisfaction index can be calculated by using the 3 satisfaction questions and their associated weightings.
- In comparison with similar, but more generic studies, the model presented in this research can be developed to accommodate more specific and detailed measure variables for measurements and validations.
- The study is based on 7 eHealth apps developed and deployed across 7 EU countries.
- The effect size of the quality to satisfaction relationship can be used in the design phase of health information systems to trade-off between alternative features.
- For health information systems, quality improvements, or differences can be estimated by changes in the satisfaction index.

Limitation

- The study does not evaluate actual system adoption among users.
- The study is specific to health information systems and EU users.
- The study does not extend to consider the impact of the system provider, organization, or other environmental factors on user satisfaction.

What was already known before on the topic?

- The general impact of qualities on user satisfaction has been investigated intensively in the studies which are based on D&M IS (success and satisfaction) and CSI (satisfaction), and less directly on TAM (acceptance) models.

What did this study add to our knowledge?

- Which specific qualities patient users across the EU considered most important.
- Which specific qualities health care professional users across the EU considered most important.
- What the weights of measure variables are for calculating the satisfaction index for health information systems.

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9.7 Authors' Contributions

SE drafted the manuscript and incorporated the contributions from other authors, contributed to the design of the study, developed the proposed models and methods, and analyzed results. JB contributed to the design of the study, supervised the research process, and critically reviewed the manuscript. TL contributed to the design of the study and critically reviewed the manuscript. MF facilitated the collection of data and critically reviewed the manuscript. PA contributed to the design of the study, contributed to the method development, supervised the research process, and critically reviewed the manuscript.

9.8 Conflicts of Interest

NONE declared.

Original Paper

Most Influential Qualities in Creating Satisfaction Among the Users of Health Information Systems: Study in Seven European Union Countries

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Abstract

Background: Several models suggest how the qualities of a product or service influence user satisfaction. Models such as the Customer Satisfaction Index (CSI), Technology Acceptance Model (TAM), and Delone and McLean Information Systems Success demonstrate those relations and have been used in the context of health information systems.

Objective: This study aimed to investigate which qualities foster greater satisfaction among patient and professional users. In addition, we are interested in knowing to what extent improvement in those qualities can explain user satisfaction and whether this makes user satisfaction a proxy indicator of those qualities.

Methods: The Unified eValuation using ONtology (UVON) method was used to construct an ontology of the required qualities for 7 electronic health (eHealth) apps being developed in the Future Internet Social and Technological Alignment Research (FI-STAR) project, a European Union (EU) project in electronic health (eHealth). The eHealth apps were deployed across 7 EU countries. The ontology included and unified the required qualities of those systems together with the aspects suggested by the Model for Assessment of Telemedicine apps (MAST) evaluation framework. Moreover, 2 similar questionnaires for 87 patient users and 31 health professional users were elicited from the ontology. In the questionnaires, the user was asked if the system has improved the specified qualities and if the user was satisfied with the system. The results were analyzed using Kendall correlation coefficients matrices, incorporating the quality and satisfaction aspects. For the next step, 2 partial least squares structural equation modeling (PLS-SEM) path models were developed using the quality and satisfaction measure variables and the latent construct variables that were suggested by the UVON method.

Results: Most of the quality aspects grouped by the UVON method are highly correlated. Strong correlations in each group suggest that the grouped qualities can be measures that reflect a latent quality construct. The PLS-SEM path analysis for the patients reveals that the effectiveness, safety, and efficiency of treatment provided by the system are the most influential qualities in achieving and predicting user satisfaction. For the professional users, effectiveness and affordability are the most influential. The parameters of the PLS-SEM that are calculated allow for the measurement of a user satisfaction index similar to CSI for similar health information systems.

Conclusions: For both patients and professionals, the effectiveness of systems highly contributes to their satisfaction. Patients care about improvements in safety and efficiency, whereas professionals care about improvements in the affordability of treatments with health information systems. User satisfaction is reflected more in the users' evaluation of system output and fulfillment of expectations but slightly less in how far the system is from ideal. Investigating satisfaction scores can be a simple and fast way to infer if the system has improved the abovementioned qualities in treatment and care.

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Figure 9.1: JMIR 2018: Most Influential Qualities in Creating Satisfaction Among the Users of Health Information Systems: Study in Seven European Union Countries

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Appendices

9.A Summary of the FI-STAR trial cases

IN Tromsø, Norway, two mobile apps — integrated at the backend — were developed to record biometric parameters and provide remote counselling and community services. In Krakow, Poland, a tele-care cloud solution monitors both preoperative rehabilitation in thoracic-surgical treatments and the physical and psychological state of patients during chemotherapy. In Munich, Germany, a surgical operating theatre monitoring system tracks and reports the consumables used during an operation. No patient questionnaire was delivered for this case. In Bilbao, in the Basque country of Spain, a telemedicine cloud solution provides treatment management for patients with bipolar disorder. In Bucharest, Hungary, a telemedicine cloud solution provides at-home cardiac rehabilitation services by monitoring and measuring biometrics. In Bologna, Italy, a telemedicine cloud solution assists in the treatment of chronic obstructive pulmonary disease (COPD) by collecting and reporting patients' vital parameters, and providing those parameters through tele-monitoring to medical personnel. One of the FI-STAR trial cases was being held in Leeds in the United Kingdom (UK), to provide a cloud solution for ensuring drug authenticity and preventing dispensing errors. The requirement documents from this case contributed to the creation of the questionnaires, but the data was not available in the evaluation phase. Accordingly, we could not use it as an input for our study. There was also a late-joining trial in Munich in which its requirements were not included during the creation of the questionnaires, but the users eventually participated in answering them. The details of each trial case can be found in the EU CORDIS database³⁴ or FI-STAR project websites.⁷⁸

78: Fricker et al. 2015

9.B Questionnaire for the patients

Please, refer to Appendix A.

9.C Questionnaire for the health professionals

Please, refer to Appendix B.

9.D Effect size and power analysis

Antecedent to Satisfaction	Patient		Professional	
	f^2	power	f^2	power
Affordability			1.51	>0.99
Effectiveness	0.14	0.93	1.66	>0.99
Efficiency	0.07	0.67		
Safety	0.10	0.84		

Table 9.11: Effect size and power of the quality to success relationships.

9.E Crossloadings in the path models

Table 9.12: Cross-loadings in the patient path model.

	Adhereability	Affordability	Effectiveness	Efficiency	Empowerment	Safety	Satisfaction	Trustability
pa.adhereability	1.00	0.28	0.41	0.22	0.29	0.59	0.44	0.22
pa.affordability	0.28	1.00	0.40	0.16	0.07	0.24	0.27	-0.10
pa.effectiveness.1	0.12	0.28	0.53	-0.23	-0.11	0.18	0.22	-0.17
pa.effectiveness.2	0.31	0.37	0.89	0.33	0.24	0.48	0.57	0.16
pa.effectiveness.3	0.47	0.25	0.81	0.21	0.17	0.55	0.38	0.11
pa.efficiency.1	0.19	0.08	0.22	0.91	0.17	0.18	0.30	0.18
pa.efficiency.2	0.03	0.19	0.04	0.67	0.13	0.07	0.15	0.19

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Table 9.12 – *continued from the previous page*

	Adhereability	Affordability	Effectiveness	Efficiency	Empowerment	Safety	Satisfaction	Trustability
pa.efficiency.3	0.27	0.17	0.26	0.93	0.13	0.27	0.38	0.24
pa.empowerment	0.29	0.07	0.19	0.17	1.00	0.35	0.26	0.07
pa.general.sat.1	0.42	0.33	0.45	0.22	0.25	0.50	0.87	0.07
pa.general.sat.2	0.36	0.20	0.51	0.31	0.30	0.45	0.85	0.12
pa.general.sat.3	0.22	0.07	0.34	0.32	0.01	0.28	0.58	0.28
pa.safety.1	0.62	0.22	0.47	0.19	0.36	0.86	0.40	0.20
pa.safety.2	0.49	0.25	0.50	0.10	0.22	0.82	0.45	0.08
pa.safety.3	0.33	0.12	0.39	0.26	0.27	0.74	0.45	0.51
pa.trustability	0.22	-0.10	0.10	0.24	0.07	0.33	0.18	1.00

Table 9.13: Cross-loadings in the professional path model.

	Accessability	Adherability	Affordability	Availability	Effectiveness	Efficiency	Empowerment	Safety	Satisfaction	Trustability
pr.accessibility	1.00	-0.01	0.21	0.56	0.44	0.26	0.34	0.39	0.44	0.51
pr.adhereability	-0.01	1.00	0.66	-0.14	0.29	0.35	0.26	0.58	0.45	0.30
pr.affordability	0.21	0.66	1.00	0.29	0.34	0.62	0.42	0.64	0.73	0.69
pr.availability	0.56	-0.14	0.29	1.00	0.63	0.52	0.60	0.23	0.51	0.37
pr.effectiveness.1	-0.11	-0.01	-0.22	0.21	0.41	-0.06	0.29	-0.02	0.22	-0.47
pr.effectiveness.2	0.34	0.34	0.43	0.56	0.78	0.55	0.63	0.46	0.67	0.39
pr.effectiveness.3	0.46	0.28	0.33	0.53	0.87	0.54	0.54	0.43	0.67	0.51
pr.effectiveness.4	0.40	0.16	0.19	0.53	0.90	0.47	0.73	0.45	0.58	0.21
pr.efficiency.1	0.15	0.30	0.55	0.42	0.30	0.76	0.49	0.51	0.45	0.17
pr.efficiency.2	0.37	0.23	0.47	0.54	0.57	0.92	0.62	0.45	0.50	0.38
pr.efficiency.3	0.13	0.35	0.53	0.34	0.55	0.81	0.45	0.26	0.52	0.57
pr.empoverment.1	0.39	0.07	0.20	0.67	0.75	0.60	0.91	0.39	0.45	0.22
pr.empoverment.2	0.25	0.39	0.54	0.46	0.62	0.56	0.94	0.58	0.55	0.19

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Table 9.13 – *continued from the previous page*

	Accessability	Adherability	Affordability	Availability	Effectiveness	Efficiency	Empowerment	Safety	Satisfaction	Trustability
pr.general.sat.1	0.32	0.45	0.71	0.41	0.64	0.47	0.45	0.61	0.90	0.49
pr.general.sat.2	0.26	0.56	0.63	0.42	0.64	0.63	0.65	0.66	0.79	0.36
pr.general.sat.3	0.49	0.00	0.34	0.39	0.50	0.29	0.16	0.32	0.67	0.65
pr.safety.1	0.50	0.54	0.39	0.12	0.32	0.24	0.27	0.82	0.44	0.42
pr.safety.2	0.40	0.61	0.50	0.09	0.27	0.25	0.26	0.84	0.51	0.44
pr.safety.3	0.31		0.25	0.48	0.50	0.47	0.68	0.57	0.51	0.28
pr.safety.4	-0.01	0.29	0.51	0.23	0.32	0.44	0.47	0.65	0.45	0.16
pr.safety.5	0.40	0.48	0.39	-0.04	0.24	0.04	0.36	0.76	0.36	0.33
pr.safety.6	0.12	0.55	0.64	0.03	0.41	0.51	0.23	0.62	0.55	0.54
pr.trustability	0.51	0.30	0.69	0.37	0.36	0.46	0.22	0.52	0.61	1.00

A Novel Instrument for Measuring Older People's Attitudes Toward Technology (TechPH): Development and Validation

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Abstract

Background The use of health technology by older people is coming increasingly in focus with the demographic changes. Health information technology is generally perceived as an important factor in enabling increased quality of life and reducing the cost of care for this group. Age-appropriate design and facilitation of technology adoption are important to ensure functionality and removal of various barriers to usage. Development of assessment tools and instruments for evaluating older persons' technology adoption and usage as well as measuring the effects of the interventions are of high priority. Both usability and acceptance of a specific technology or service are important factors in evaluating the impact of a health information technology intervention. Psychometric measures are seldom included in evaluations of health technology. However, basic attitudes and sentiments toward technology (eg, technophilia) could be argued to influence both the level of satisfaction with the technology itself as well as the perception of the health intervention outcome.

Objective The purpose of this study is to develop a reduced and refined instrument for measuring older people's attitudes and enthusiasm for technology based on relevant existing instruments for measuring technophilia. A requirement of the new instrument is that it should be short and simple to make it usable for evaluation of health technology for older people.

Methods Initial items for the TechPH questionnaire were drawn from a content analysis of relevant existing technophilia measure instruments. An exploratory factor analysis was conducted in a random selection of persons aged 65 years or older ($N=374$) on eight initial items. The scale was reduced to six items, and the internal consistency and reliability of the scale were examined. Further validation was made by a confirmatory factor analysis (CFA).

Results The exploratory factor analysis resulted in two factors. These factors were analyzed and labeled techEnthusiasm and techAnxiety. They demonstrated relatively good internal consistency (Cronbach $\alpha=.72$ and $.68$, respectively). The factors were confirmed in the CFA and showed good model fit ($\chi^2_8=21.2$, $\chi^2/df=2.65$, comparative fit index=0.97, adjusted goodness-of-fit index=0.95, root mean square error of approximation=0.067, standardized root mean square residual=0.036).

Conclusions The construed TechPH score showed expected relations to external real-world criteria, and the two factors showed interesting internal relations. Different technophilia personality traits distinguish clusters with different behaviors of adaptation as well as usage of new technology. Whether there is an independent association with the TechPH score against outcomes in health technology projects needs to be shown in further studies. The instrument must also be validated in different contexts, such as other countries.

Keywords

technophilia; aging; internet; health technology; eHealth

10.1 Introduction

10.1.1 Background

OLDER people's use of technology is increasingly coming in focus with the demographic changes. Gerontechnology (technology for the aging population) is a growing field in transdisciplinary research as well as in the development of new products.^{1,2} Previous research into older people's technology use has identified that the design^{3,4} and technology adoption^{5,6} perspectives are important to ensure appropriate functionality and remove various barriers for use. Personal factors, such as self-efficacy and proficiency,^{5,7,8} as well as subjective technology adaptivity^{9,10} have also been identified as significant predictors of technology use in old age.

One area that has attracted interest is the use of technology by older adults in various health settings, both in formal health care^{11,12} and from salutogenic perspectives^{13,14} targeting social isolation and participation. However, there is a strong need to find evidence of the effectiveness and efficiency of health technology interventions, which is becoming increasingly important as the number of available health technology solutions grows.¹⁵

SEVERAL instruments for evaluating interactions with health technology exist today. Common theoretical concepts addressed in those instruments are effectiveness, efficiency, hardware/software, perceived ease of use, and satisfaction, although validated psychometric instruments measuring personality traits are sparse.¹⁶

One of the most widely used instruments is the Technology Acceptance Model (TAM)¹⁷ and its subsequent developments¹⁸ for evaluating attitudes predicting intentions to use and how users come to accept and use a particular information technology. In this model, two specific factors determine the user's acceptance: perceived usefulness (PU) and perceived ease of use (PEOU). Although TAM was not developed specifically for health information technology (HIT) it has found its way into

1: Schulz et al. 2015

2: Kwon 2016

3: Peine 2019

4: Czaja et al. 2019

5: Mitzner et al. 2019

6: Czaja et al. 2006

7: Roque et al. 2018

8: Boot et al. 2015

9: Kamin et al. 2017

10: Kamin et al. 2013

11: Ramprasad et al. 2019

12: Jakobsson et al. 2019

13: Barbosa Neves et al. 2019

14: Baker et al. 2018

15: Enam et al. 2018

16: Wakefield et al. 2017

17: Davis 1989

18: Venkatesh et al. 2003

this area as a measurement of end users' reactions to HIT.¹⁹ Expansions to adapt TAM to a more specific HIT context have been made: Health Information Technology Acceptance Model (HITAM).²⁰ Application and problematization of TAM towards older persons have also been made: Senior Technology Acceptance Model (STAM)²¹ and HITAM of older persons.²² The importance of contextual factors,^{23,24} as well as the usability and acceptability for older adults with mild cognitive impairment and dementia²⁵ have recently been in focus.

Another widely used model is the Delone and McLean Information Systems Success (D&M IS) model, which considers constructs of intention to use, user satisfaction, and net benefits as the outcomes of three sets of indicators that are information quality, service quality, and system quality.²⁶ The D&M IS model and its extended variants, such as Human, Organization, and Technology Fit (HOT-fit),²⁷ have been widely used in health technology.²⁸ How traits affected by or closely related to technophobia, such as technostress,²⁹ can impact the satisfaction construct in the D&M IS model has been discussed.³⁰

Usability is another essential aspect of HIT evaluation. Both the design and evaluation of artifact, efficiency, effectiveness, and satisfaction are important. The Health Information Technology Usability Evaluation Scale (Health-ITUES)³¹ and the System Usability Scale (SUS)³² are instruments for usability evaluation that have been used in a HIT context.^{33,34} In what is an extension of the TAM perspective, Kamin and Lang¹⁰ explored the motivational resources for older persons' technology use by the concept of subjective personal adaptivity. They found that positive beliefs about the benefits of technology, the time and effort invested to learn how to use technology, and a sense of trustworthiness and safety while using technology is connected to both perceived technology competence and technology usage.

Usability, acceptance, motivation, and adoption of a specific technology or service are important factors in evaluating the impact of a HIT intervention. However, basic attitudes and sentiments toward technology (eg, technophilia) could be argued to influence both the level of satisfaction with the technology itself as well as the perception of the health intervention outcome. This would constitute a personality trait, an underlying factor that would create a preintervention entry level of acceptance and interest, positive or negative. Edison and Geissler³⁵ argue that this "affinity" toward technology is a more general attitude that precedes the more specific attitudes resulting from the rational (reasoned

19: Holden et al. 2010

20: Kim et al. 2012

21: Chen et al. 2014

22: Middlemass et al. 2017

23: Merkel et al. 2016

24: Peek et al. 2016

25: Holthe et al. 2018

26: DeLone et al. 1992

27: Yusof et al. 2006

28: Yu et al. 2009

29: Self et al. 2013

30: Tarafdar et al. 2010

31: Yen et al. 2010

32: Brooke 1996

33: Georgsson et al. 2016

34: Schnall et al. 2018

35: Edison et al. 2003

or planned) process that is measured in TAM. Plociennik et al³⁶ found that technophilia has a direct influence on PU, in TAM. Ronit³⁷ sees technophilia as the enthusiasm toward technology with its rewarded and knowledgeable adoption correlated with both PU and PEOU. Kamin and Lang^{9,10} showed a correlation between usability and utility and a subjectively perceived interest and competence.

36: Plociennik et al. 2010

37: Ronit 2011

10.1.2 *Technophilia*

TECHNOPHILIA has no universally established definition but generally refers to a strong enthusiasm and love for modern technology. Seebauer et al³⁸ define it as “an attitude toward ICT [internet and communication technology], representing a subaspect of technology-related values, just as ICT are a subcategory of modern technology.” Osiceanu³⁹ defines technophilia as an “attraction, enthusiasm of the human individual determined by the activities which involve the use of advanced technologies. It is expressed by easy adaptation to the social changes brought by technological innovations.” Martínez-Córcoles et al⁴⁰ suggest that merely enthusiasm and desire is not enough for technophilia, but also an acquired need for (dependency) and joy of having and displaying the latest products/versions (technoreputation). In a working paper, Li and Fuller⁴¹ suggest a definition of technophilia as “positive affective states that arise momentarily in response to an individual's ICT context that is appraised to exceed his or her expectations and goals.”

38: Seebauer et al. 2015

39: Osiceanu 2015

40: Martínez-Córcoles et al. 2017

41: Li et al. 2017

In their review of previous related research on technophilia and similar concepts, Seebauer et al³⁸ found three hierarchically nested perspectives on technophilia. At the top level, they found values connected to general technology-related values reflecting global beliefs in societal progress through technology. At the intermediate level were attitudes referring more specifically to information and communication technology (ICT) as a part of modern technologies. The lowest level was constituted by a keen interest in and use of a specific technology or service as a subcategory of ICT. Openness toward technology and innovation influences personal dedication to certain technological artifacts and services, whereas feelings of low enthusiasm may work in the opposite direction.³⁸ Donat et al⁴² refer to this lower (negative) end of technology enthusiasm as technophobia, and their construct is made up from two opposite ends where technophilia is at the positive end. Nimrod⁴³ includes this positive end of the spectrum in her construct of a technophobia scale while

42: Donat et al. 2009

43: Nimrod 2018

investigating ICT use among older adults. Osiceanu³⁹ further views technophobia as the negative feelings about using technology, but also includes perceptions on the adverse effects that technology may have on society in the construct. This is a common way to conceptualize technophobia construct with both factors concerning personal feelings toward technology use together with overall perceptions of technology in society.

IN this study, we choose to avoid the complexity of bringing the two concepts of technophilia and technophobia together and simply let technophilia refer to a person's enthusiasm for and positive feelings toward their technology use and absence of the fears and doubts some older people could have about their ability to manage using new technology. It constitutes a personality trait, an underlying psychological construct³⁸ that would create a pretechnology and preintervention entry level of acceptance and interest. This could also be connected to other psychological characteristics (ie, the personality traits of openness and neuroticism).⁴⁴

44: Devaraj et al. 2008

Steinerman et al⁴⁵ report that technophilia is a consistent predictor of openness to research participation for older adults and that research with older adults that incorporates technology should consider technophilia to be more successful in recruiting participants for the study.

45: Steinerman et al. 2013

Older people compared to younger persons are sometimes reported to score lower on technophilia scales.³⁸ Still, older people are not a homogeneous group, and there may be differences between "younger" old and "older" old individuals. Therefore, it is of importance to create an instrument with the ability to discriminate between high and low technophilia individuals within various groups of older people.

10.1.3 Objectives

THE purpose of this study is to develop a reduced and refined instrument for measuring older people's attitudes and enthusiasm for technology based on relevant existing instruments for measuring technophilia (named TechPH, short for technophilia).

Technophilia is a general quality for any individual's relationship to technology that could potentially influence a wide range of aspects of technology use, such as adoption, continuity, and perceived outcome.

In this text, we contextualize this general quality with a focus on

older people for use in health technology intervention research as a complement to existing instruments. The new instrument requires that it should be short and simple to make it usable for older people.

10.2 *Methods*

10.2.1 *Data Collection and Sample*

DATA were obtained from a sample of participants in the Swedish National Study on Aging and Care (SNAC). SNAC is a longitudinal cohort study of a representative sample of the aging Swedish population that began data collection in 2001. It is a comprehensive, interdisciplinary study that investigates the health and living conditions of the Swedish population aged 60 years and older. A detailed outline of the SNAC study is available by Lagergren et al.⁴⁶ Our study sample was based on participants from one of the four regions in the SNAC study, the SNAC Blekinge (SNAC-B) cohort with individuals living in the municipality of Karlskrona.

46: Lagergren et al. 2004

Data were collected through a questionnaire that was sent out in October 2017 to all participants in the SNAC-B study who were alive in January 2017 (N=878). Of these, 18 had deceased before answering the questionnaire. A total of 659 persons responded, corresponding to a response rate of 77% (659/860). Among nonresponders, 28% (57/201) were unable to respond due to their health conditions (eg, severe dementia or other diseases) and were considered nonusers of ICT. In this study, only individuals who responded that they were ICT users were included (N=374). Demographic data for the study population (ie, age, gender, and educational level) are presented in Table 10.1.

10.2.2 *Measures and Scale Development*

DEVELOPMENT of the new short instrument, TechPH, was made in three steps. First, a search was made in *Web of Science* and *Google Scholar* for technophilia measurement instruments to use as a background for building the new instrument. To be included, the articles had to contain a psychometric instrument for use on the individual level. Eight relevant instruments were found to match the criteria (Multimedia Appendix 1), of which seven reported a full instrument and were included in this study. Instrument 8⁴⁰ did not include the full instrument in their article

Category	Participants	
Sex, n(%)	Male	196 (52.4)
	Female	178 (47.6)
Age (years), mean (SD)		72.6 (7.1)
	65-75	232 (62.0)
	75-96	142 (38.0)
Education level ^a , n (%)	Low	94 (26.0)
	Medium	135 (38.0)
	High	131 (36.0)

Table 10.1: Demographic data for the study population, including age, gender, and educational level (N=374)

^a N=360 for education level. Education was categorized in three groups according to the previous Swedish education system, relevant for the age groups in this study (low: those who did not finish secondary school; medium: those who finished secondary school but no further education; high: those with some form of higher education).

and could not be used in the content analysis. Overarching themes (emotional, personal gain, openness/curiosity, competence, general attitudes) were identified through content analysis and items corresponding to these themes were constructed with a five-point Likert scale questionnaire, ranging from 1 (fully disagree) to 5 (fully agree). Following the instruments in the analysis, both questions with a positive and a negative direction were constructed to make sure both the lower and the higher end of the spectrum of technophilia were sufficiently covered. The instruments used in the analysis also gave reason to assume that more than one factor could be present. A total of six to eight questions was considered ideal both for the length of the instrument and for the case that more than one factor would emerge from the factor analysis.

The new instrument resulting from the content analysis was able to build on the previous instruments by including all themes in the same instrument. The analysis showed that none of the seven existing instruments investigated covered all the themes resulting from the analysis, making the new developed short instrument (TechPH) more comprehensive than its predecessors.

Expert knowledge in gerontology from both the medical side (geron-

tologist) and the technical side (design expert) was used to phrase and formulate the questions for the target group.

Secondly, the questionnaire was pretested and cognitive interviews⁴⁷ were made with the target group (eight individuals of both sexes varying in age between 60 and 82 years). The interview persons were given the 8-item questionnaire and were encouraged to think-aloud when they read them. The interviewer would also follow-up with verbal probing (ie, questions about how the interview persons understood the question) based on item wording, terminology, and if the structure was clear and easy to understand. Specifically, the questions "Can you repeat the question I just asked in your own words? Was there anything confusing about this question? What does the word <term> mean to you as it is used in the question? Tell me what you were thinking when I asked about <topic of question>."

47: Peterson et al. 2017

The item questions were then revised according to the feedback from the interviews with respect to the verbal probing. Especially important was to make sure that the questionnaire was using terminology relevant to older people using technology to ensure face validity. The resulting questionnaire items (Table 10.2) was also pretested on four persons from the target group.

FINALLY, factor analyses were made. First exploratory factor analysis (EFA) to see the factor structure and decide on a one or multiple factor solution. Before the exploratory factor analysis, Bartlett test of sphericity was used to ensure significant correlation and Kaiser-Meyer-Olkin (KMO) test of sampling adequacy for sufficient variance among the items. Maximum likelihood factoring and Promax with Kaiser normalization were used, and only factors with eigenvalues greater than 1 were included.

The reliability of the questionnaire was calculated with the Cronbach alpha coefficient to ensure sufficient internal consistency.

Confirmatory factor analysis (CFA) was then used to verify the factor structure. Measures of fit are reported, such as chi-square statistic and its significance, the adjusted goodness-of-fit index (AGFI), the comparative fit index (CFI), the root mean square error of approximation (RMSEA), and the standardised root mean square residual (SRMR).

48: DiStefano et al. 2009

FINALLY, an index based on sum scores was calculated,⁴⁸ and sociodemographic attributes and self-assessed technical competence were as-

sessed for group comparisons and as indicators of criterion validity.

Table 10.2: Descriptive statistics of suggested instrument items (N=374).

Questionnaire item	Mean (SD)	Median
1. I think it's fun with new technological gadgets	3.40 (1.19)	3.00
2. Using technology makes life easier for me	3.78 (1.27)	4.00
3. I like to acquire the latest models or updates	2.53 (1.34)	2.00
4. I am sometimes afraid of not being able to use the new technical things	2.90 (1.35)	3.00
5. Today, the technological progress is so fast that it's hard to keep up	3.73 (1.22)	4.00
6. I would have dared to try new technical gadgets to a greater extent if I had had more support and help than I have today	3.10 (1.41)	3.00
7. People who do not have access to the Internet have a real disadvantage because of all that they are missing out on.	4.13 (1.16)	5.00
8. Too much technology makes society vulnerable	4.10 (1.07)	4.00

10.3 Results

10.3.1 Exploratory Factor Analysis

THE KMO test of sampling adequacy was in the adequate range of 0.76⁴⁹ and Bartlett's test of sphericity ($\chi^2_{28}=554.1$) was significant ($P<.001$), indicating that the items were appropriate for a factor analysis.⁵⁰

49: DiIorio 2006

50: Hair et al. 2010

A two-factor solution for technophilia emerged with an eigenvalue greater than 1 and examination of the scree plot. A one-factor solution was also tested for but showed low internal consistency and was discarded. The two factors were distinctly different with respective clear loadings. The factor with questions regarding positive feelings toward technology

(ie, items 1-3) contained items with various aspects of enthusiasm toward technology was accordingly named *techEnthusiasm*. The factor with more negative feelings (items 4-6), contained items with different aspects of anxiety toward technology with respect to use and competency and was named *techAnxiety*.

The questions regarding general attitudes (items 7 and 8) gave low loadings and cross-loaded on both factors above the recommended maximum threshold of 0.32;⁵¹ therefore, they were removed.

51: Osborne et al. 2004

The final six-item solution (Table 10.3) gave satisfactory loadings of above 0.5⁵⁰ and a total variance explained of 63.5% for the two factors together.

Convergent validity with average variance extracted above 0.5⁵⁰ and discriminant validity shown with only small cross-loadings, together with a factor correlation of $-.48$. The reliability of the questionnaire, in terms of internal consistency, was calculated by Cronbach alpha (Table 10.3) with satisfactory results for the small item number (techEnthusiasm Cronbach alpha=.72 and techAnxiety Cronbach alpha=.68).

Item	techEnthusiasm	techAnxiety
1. I think it’s fun with new technological gadgets	0.86	0.01
2. Using technology makes life easier for me	0.62	0.04
3. I like to acquire the latest models or updates	0.60	-0.02
4. I am sometimes afraid of not being able to use the new technical things	-0.07	0.68
5. Today, the technological progress is so fast that it’s hard to keep up	0.00	0.75
Item6. I would have dared to try new technical gadgets to a greater extent if I had had more support and help than I have today	0.09	0.53
Cronbach alpha	.72	.68

Table 10.3: Exploratory factor analysis loadings and Cronbach alphas.

10.3.2 Confirmatory Factor Analysis

THE final confirmatory factor analysis (CFA) conducted showed relatively good⁵² fit indexes for the two-factor model ($\chi^2_8=21.2$, $\chi^2/\text{df} = 2.65$, CFI = 0.97, AGFI = 0.95, RMSEA = 0.067, SRMR = 0.036). The model showed satisfactory (>0.5) standardized factor loadings given the sample size⁵⁰ confirming construct validity. Table 4 shows the standardized parameter estimates.

52: Hu et al. 1999

Item	Loadings	
	techEnthusiasm	techAnxiety
1. I think it's fun with new technological gadgets	0.88	
2. Using technology makes life easier for me	0.63	
3. I like to acquire the latest models or updates	0.61	
4. I am sometimes afraid of not being able to use the new technical things		0.74
5. Today, the technological progress is so fast that it's hard to keep up		0.72
6. I would have dared to try new technical gadgets to a greater extent if I had had more support and help than I have today		0.53

Table 10.4: Confirmatory factor analysis standardized factor loadings for TechPH. Blank cells are not applicable.

10.3.3 TechPH Index

A composite score⁵⁰ (see Table 10.5) was created from the six items in the two factors, techEnthusiasm and techAnxiety (the latter reversely coded due to the negative correlation). Each item was weighted with its loading before sum scores were created and averaged⁴⁸ and standardized back to a 1 to 5 scale so that the TechPH index could be interpreted on a five-point response scale, ranging from 1 (fully disagree) to 5 (fully agree), where the higher the index indicates a higher level of technophilia.

Distribution of all individuals' scores in the two factors, techEnthusiasm and techAnxiety, is presented in a scatterplot (see Figure 10.2). A low negative correlation between the two factors was observed ($R^2=.12$).

10.3.4 Group Comparison

THE TechPH index (Table 10.5) was used for group comparison for gender, age group, level of education, self-assessed technical skills, and internet use frequency. This comparison yielded significant ($P<.05$) results. Cronbach alpha was .71, which signifies moderately good reliability of the index and internal consistency.

The TechPH index scores reflect the same finding or assumptions in technology acceptance by demographic variables; the index decreases in the older old (≥ 75 years) group and is slightly higher for men, which confirms other findings with regard to age groups and gender.⁵³

53: Or et al. 2009

10.4 Discussion

THIS project set out to create a short instrument to enable measuring of technophilia for use among older persons participating in health technology research projects. The requirements were that it should be based on existing validated instruments and that it should be short and simple to make it usable for older people.

The resulting instrument consists of six items in two factors measuring techEnthusiasm and techAnxiety as factors of technophilia. Factor analysis of the instrument showed the feasibility of a two-factor model. Better fit for a two-factor model, compared to a one-factor model, shows that techEnthusiasm and techAnxiety are not just inverse ends of the same continuum, but two independent factors that could influence various aspects of the use of technology. There is a slight reverse correlation between them (Figure 10.2).

THE results in Table 10.5 complies with general findings, and assumptions about gender, age, technical skills, and internet use frequency correlates with technology adoption. The correlation between technical skills and TechPH confirms other findings regarding reduced fear of technology by gaining technical skills.^{54,55} Seifert and Schelling⁵⁶ showed that affinity for technology has a positive impact on internet use. This is also consistent with the findings of Nimrod⁴³ with similar relations

54: Wild et al. 2012

55: Shedletsky 2006

56: Seifert et al. 2018

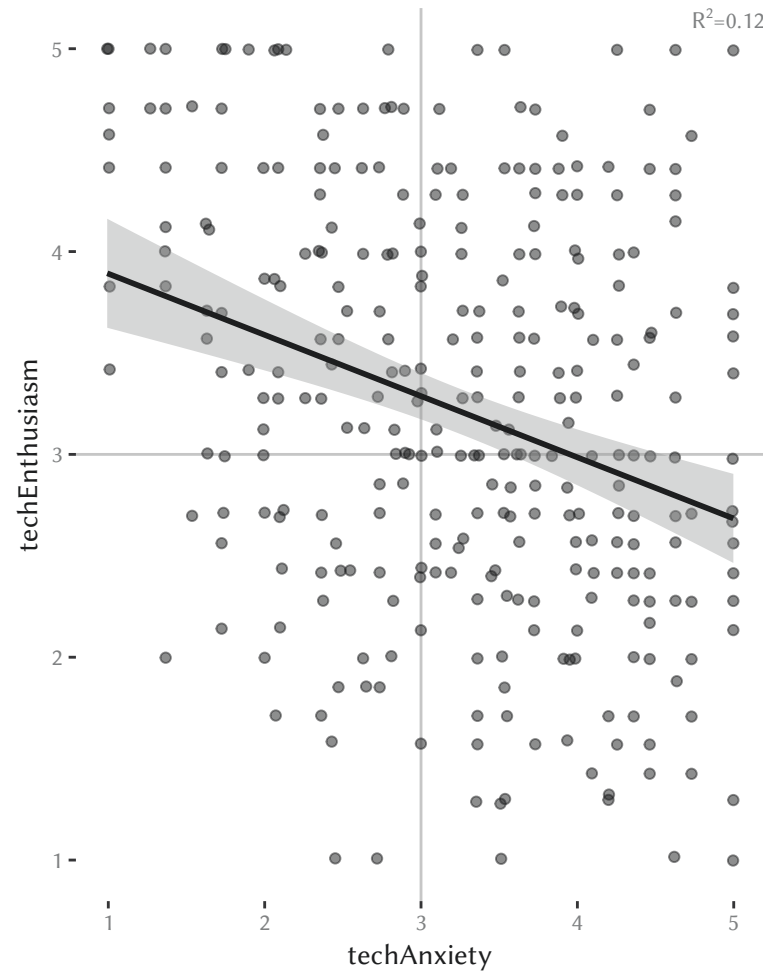


Figure 10.2: Scatterplot of techEnthusiasm (y-axis) and techAnxiety (x-axis). Individuals showing high technophilia (TechPH) are found in the second quadrant; low TechPH are found in the fourth quadrant.

Table 10.5: TechPH index: descriptives and group test statistics.

Group	N	TechPH index, mean (SD)	<i>t</i> test (<i>df</i>)	<i>F</i> test (<i>df1</i> , <i>df2</i>)	<i>P</i> value
All	374	3.01 (0.86)	— ^a	—	—
Gender			1.71 (372)	—	.046
Men	196	3.08 (0.88)			
Women	178	2.93 (0.82)			
Age (years)			2.89 (372)	—	.004
< 75	232	3.11 (0.81)			
≥ 75	142	2.85 (0.90)			
Education			—	0.65 (2,357)	.52
Low	94	2.96 (0.92)			
Medium	135	2.96 (0.81)			
High	131	3.07 (0.87)			
Self-assessed technical skill ^b			—	86.40 (2,337)	<.001 ^c
Low	105	2.38 (0.64)			
Medium	200	3.18 (0.70)			
High	35	4.02 (0.82)			
Internet use frequency ^d			—	29.26 (2,338)	<.001 ^c
Low	77	2.59 (0.82)			
Medium	104	2.87 (0.67)			
High	160	3.38 (0.84)			

^a Not applicable.
^b “How skilled do you consider yourself when it comes to using a smartphone or a tablet?” Low=not at all skilled, medium=average skilled, high=very skilled.
^c All post hoc (Tukey) group mean differences were significant at the .05 level.
^d The participants were categorized as high=daily, medium=at least once a week but not daily, low=less than once a week.

to education, gender, and age, as well as use of technology (in this case, the internet) as in our study. Nimrod investigated technophobia with Sinkovics et al.⁵⁷ with a 13-item and 3-factor instrument (personal failure, human versus machine ambiguity, perceived convenience). This is a similar setup to TechPH, with different factors pointing both to a lower and higher end of the technophilia/technophobia spectrum. Nimrod measured technophobia specifically toward ICT, such as “computers, internet, and mobile phones,” thus making some of the questions border a measure of a utility perspective rather than a personality trait with feelings toward technology in general.

CONCERNING techEnthusiasm, item 1 (“I think it’s fun with new technological gadgets”) loaded strongly on the techEnthusiasm factor, which was expected based on the theoretically assumed relationship with the latent variable, confirming that an item (observed variable) that closely reflects the latent variable should be highly correlated with that for a valid model. Item 2 (“Using technology makes life easier for me”) and item 3 (“I like to acquire the latest models or updates”) loaded somewhat weaker but are still seen as conceptually valid for the construct as a whole.

On the techAnxiety side, item 4 (“I am sometimes afraid of not being able to use the new technical things”) closely reflects techAnxiety both in articulation and relatively high correlation. It should be noted that this item considers an internal cause, that is an inability to use technology. Item 5 (“Today, the technological progress is so fast that it’s hard to keep up”) reflects the anxiety over a perceived inability to internalize and relate to the fast, technological progress and connects to a “technostress”.⁵⁸ Item 6 (“I would have dared to try new technical gadgets to a greater extent if I had had more support and help than I have today”) refer to the anxiety older people can feel about their lacking ability to handle technology on their own and fear of social isolation and lack of support of the aging population.⁵⁹

58: Nimrod 2018

59: Berner et al. 2015

The two questions regarding general attitudes, items 7 and 8 (ie, “People who do not have access to the internet have a real disadvantage because of all that they are missing out on” and “Too much technology makes society vulnerable”), did not load sufficiently on any of the factors and did not make up a factor of their own. Both these items showed high means and medians and had poor discriminant value, signifying that these attitudes are shared between persons both with high and low

techPH. This result is similar to that of Seifert and Schelling,⁵⁶ in which both onliners and offliners with a high affinity for technology attributed a high value to the internet (in this case, for staying independent longer in old age).

IT might be assumed that a high techEnthusiasm score is associated with a low techAnxiety score and vice versa, but it is still possible that both scores could be high or low together. This could have implications for a medium score and needs to be investigated further when TechPH is tested in health technology projects.

An interpretation of a set of high scores in both techEnthusiasm and techAnxiety factors could be that the individual has a basic positive attitude or enthusiasm to technology, but also feels limitations. A lack of interest in technology could be the reason why a person might show low degrees of technology enthusiasm and anxiety simultaneously. However, this lack of interest in technology does not necessarily indicate ignoring technology benefits in general, but it might be the personal attitude about their necessity for the current situation of the respondent.²⁴

From this perspective, TechPH could be hypothesized to have an effect on the outcome that is separate from the planned intention to use or the perceived usefulness of the application itself. Another assumption is that this could have an impact on how a person perceives problems with use and nonuse friendliness and make a person more error tolerant. This could possibly skew the usability measurements and constitute a confounder to the measured health effect outcome. In smaller studies, especially in randomized controlled studies, this would be a variable of interest to study. This is similar to the effect that Kamin and Lang¹⁰ suggest while exploring the motivational resources for older persons' technology use by the concept of subjective personal adaptivity. They argue that usability testing might be misleading if motivational factors moderating task performance in person technology transactions are not considered.

Whether this is a personal trait influencing attitudes toward technology that is related to age or physical or cognitive problems will be tested in further studies. We can also assume that the impact on the factors in TechPH is affected differently depending on the type of health technology being evaluated. It could be assumed that the techAnxiety factor has a greater impact on technology that influences items such as personal privacy.

A strength of the instrument introduced in this study is that it is based on previously validated, relevant instruments. It is shortened as much as possible, to three variables per factor,⁶⁰ and articulated by expert analysis to be suitable for older people. The factor analysis is based on a satisfactory sample size of the general population of older adults from a midsized community in Sweden. Overall, the instrument performed as expected and will now be tested for its prediction ability of the outcome for a health technology project with older people.

60: Bollen 2014

IN conclusion, we suggest that different technophilia traits distinguish clusters with different behaviors of adaptation as well as usage of new technology and hypothesize that this can be measured with the TechPH score. Whether there is an independent association with the TechPH score or either of the two factors contributing to the score, techEnthusiasm and techAnxiety, against outcomes in health technology projects needs to be shown in further studies. The instrument must also be validated in different contexts, such as other countries.

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10.6 Conflicts of Interest

NONE declared.

Original Paper

A Novel Instrument for Measuring Older People's Attitudes Toward Technology (TechPH): Development and Validation

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Abstract

Background: The use of health technology by older people is coming increasingly in focus with the demographic changes. Health information technology is generally perceived as an important factor in enabling increased quality of life and reducing the cost of care for this group. Age-appropriate design and facilitation of technology adoption are important to ensure functionality and removal of various barriers to usage. Development of assessment tools and instruments for evaluating older persons' technology adoption and usage as well as measuring the effects of the interventions are of high priority. Both usability and acceptance of a specific technology or service are important factors in evaluating the impact of a health information technology intervention. Psychometric measures are seldom included in evaluations of health technology. However, basic attitudes and sentiments toward technology (eg, technophilia) could be argued to influence both the level of satisfaction with the technology itself as well as the perception of the health intervention outcome.

Objective: The purpose of this study is to develop a reduced and refined instrument for measuring older people's attitudes and enthusiasm for technology based on relevant existing instruments for measuring technophilia. A requirement of the new instrument is that it should be short and simple to make it usable for evaluation of health technology for older people.

Methods: Initial items for the TechPH questionnaire were drawn from a content analysis of relevant existing technophilia measure instruments. An exploratory factor analysis was conducted in a random selection of persons aged 65 years or older (N=374) on eight initial items. The scale was reduced to six items, and the internal consistency and reliability of the scale were examined. Further validation was made by a confirmatory factor analysis (CFA).

Results: The exploratory factor analysis resulted in two factors. These factors were analyzed and labeled techEnthusiasm and techAnxiety. They demonstrated relatively good internal consistency (Cronbach alpha=.72 and .68, respectively). The factors were confirmed in the CFA and showed good model fit ($\chi^2_4=21.2$, $\chi^2/df=2.65$, comparative fit index=0.97, adjusted goodness-of-fit index=0.95, root mean square error of approximation=0.067, standardized root mean square residual=0.036).

Conclusions: The construed TechPH score showed expected relations to external real-world criteria, and the two factors showed interesting internal relations. Different technophilia personality traits distinguish clusters with different behaviors of adaptation as well as usage of new technology. Whether there is an independent association with the TechPH score against outcomes in health technology projects needs to be shown in further studies. The instrument must also be validated in different contexts, such as other countries.

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KEYWORDS

technophilia; aging; internet; health technology; eHealth

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Figure 10.1: JMIR 2019: A Novel Instrument for Measuring Older People's Attitudes Toward Technology (TechPH): Development and Validation

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Ethical Challenges of Evaluating Health Information Systems

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Abstract

Background Evaluating and researching health information systems are interventions of their kind and might lead to ethical complexities and challenges. Most of those challenges are inherited from the more general fields of research and evaluation, health studies, and information systems studies. Beyond those challenges, this field has its particular traits, regarding the involved stakeholders, required values or qualities, or the process which can raise field-specific or context-specific ethical challenges.

Objectives This paper reports and discusses some of the challenges of evaluating and researching health information systems by taking a systematic approach in finding, postulating, and analyzing them.

Method Through a scoping review, a set of ethical challenges, regarding the evaluation and research of health information systems, were extracted. From the same set of articles, the acting entities, including stakeholders and artefacts, were identified. From a sample of seven cases of health information

systems, a set of demanded impact qualities were extracted. From the literature, the evaluation stages were elicited. The acting entities, required qualities, and the evaluation stages were combined to create a three-dimensional space. The space contained the ethical challenges extracted from the scoping review and helped to postulate more items.

Results The final list of identified items contains 20 possible ethical challenges that can be caused or raised by evaluating or researching health information systems and technologies. The ethical challenges are discussed, based on their probable stage of occurrence. The three-dimensional space and the method of populating it is proposed as an effective method in similar cases of discovering ethical challenges.

Conclusion Evaluating or researching health information systems can raise ethical challenges, that we have identified 20 of them in this article. All the challenges were discussed, such as the actual value of evaluation, breach of privacy, risks for safety, problems with usability and accessibility, conflict of interests, problems with the informed consent, and miscommunication. The novel approach for elicitation of the ethical challenges introduced in this article might be applied in other similar studies.

11.1 Introduction

THERE is a tenderness associated with the term *evaluation*, as it sounds like a silent, intangible observation with zero footprints on the subject. That is rarely true, not in a discipline based on almost-rigid rules such as physics, nor in a human-centered one such as health information technologies. Evaluation inevitably engages with its subject, in a grayscale of different levels and a plethora of simple to complex ways, and this engagement gives rise to various ethical challenges. *:ethical challenges exist, and we should deal with them*

The authors of this manuscript, previously, were involved in the evaluation of Future Internet Social and Technological Alignment Research (FI-STAR), an European Union (EU) wide project developing seven e-health software apps.^{1,2} That experience led to questions and discus-

1: FI-STAR Consortium 2014

2: Eivazzadeh et al. 2016

sions on ethical challenges of evaluating health information systems, not restricted to the evaluation of FI-STAR. The major and generic question is how the evaluation process might drive changes in perceiving, designing, implementing, delivering, operating, and maintaining health information systems in a way that might improperly affect stakeholders of those systems, leading to ethical challenges for the evaluator. A sequel question would be how we can discover those ethical challenges in a specific context, similar to the evaluation of the FI-STAR project outputs.

ETHICS of evaluating health information systems is merely a small descendant of its ancestral broader contexts. Among those ancestral contexts, one can name the ethics of evaluation in general, the ethics of evaluation in health, and the ethics of evaluation in information systems. However, the lineage does not stop there. The dominant ethical norms in those contexts drive from and relate to the most common generic ethical norms. Or from the other hand, it was the generic ethical norms of the new era which have left footprints in the small locality of the ethics of evaluating health information systems.

Traces of the aforementioned generic ethical norms can be found in various pieces of literature. Some of those generic norms are partially articulated in the United Nations (UN) declarations and treaties such as Universal Declaration of Human Rights (UDHR), International Covenant on Economic, Social and Cultural Rights (ICESCR), and International Covenant on Civil and Political Rights (ICCPR); or being embedded in the corpus of related literature, or even being acknowledged as tacit common norms between us. To give examples for the above claim, the *right to health*, which is defined in the article 12 of the ICESCR as the “right to control one’s own health and body”,³ has incarnated as the *patient consent* in many of the health-related studies. Or, the *right to privacy*, the way it is captured in the article 17 of the ICCPR and articulates as “no one shall be subjected to arbitrary or unlawful interference with his privacy”,⁴ parallels the *patient confidentiality* concept in the health studies. More specific to the research in health, codes and declarations such as the Nuremberg Code,^{5,6} the Belmont report,⁷ and the Helsinki declaration⁸ can be mentioned. These codes and declarations, explicitly or implicitly, demand specific rules and constraints to be applied in treating human subjects, as a part of the research conduct. Requirements on safety, privacy, informed consent, and risk assessment

:positioning

3: UN General Assembly 1966

4: UN General Assembly 1966

5: Shuster 1997

6: Weindling 2001

7: The United States Department of Health, Education, and Welfare 1979

8: World Medical Association 2001

are repeating themes of these works. Many of these requirements are not only applicable in conducting health research, which directly involves human subjects but also they can be extended to researching systems and technologies that are related to the health of people.

Beyond inheriting ethical norms from parental contexts, analogies can also be found in between evaluation ethics, research ethics, professionalism, and work ethics. Some researchers find little or no distinction between ethics of evaluation and research.^{9,10} And, some concepts like *objectivity*, *openness*, and *honesty* are common between ethics of evaluation, research,¹¹ and work ethics such as in the public administration.¹²

Still, the small spot of the ethics of evaluation of health information systems has its specific traits in the diversity map of the ethics-related studies; therefore, it deserves a closer look and inspection. In this paper, we address some of those traits that show up as challenges during a typical flow of evaluation of health information systems.

FOR a better understanding of the system types that the ethics of evaluation can be applied to them, we need to come to a consensus about the extents of *health information systems*. The literature of *health technology* usually defines it very broadly. For example, It has been considered health technology as “pharmaceuticals, devices, procedures, and organizational systems used in health care”.¹³ Similarly, health information systems are defined very inclusively, such as “any system that captures, stores, manages or transmits information related to the health of individuals or the activities of organizations that work within the health sector”.¹⁴ Also, the vernacular of health information system literature is populated with general terms such as e-health, digital health, health informatics and more specific terms such as electronic health record (EHR), telemedicine, m-health, where all are synonyms or subtypes of health information systems.

Because of this inclusiveness in the definitions, many technologies and information systems can be considered as types of health information systems, hence requiring health care grade ethical concerns when doing research and evaluation. For example, a simple calendar app, being used in a health care setting, might play the role of a drug-taking time-reminder. Therefore, higher degrees of ethical considerations should be taken when evaluating any app when it plays a role in a health setting. In this manuscript, we consider any system that is labeled by one of those terms in the vernacular of health information systems. Besides, cases of

9: Shaw 2003

10: Barnett et al. 2016

11: Resnik 2015

12: United Nations Secretariat 2009

:scoping: *what is the health information system*

13: Facey et al. 2006

14: Cruz-Cunha, Maria Manuela 2016

using information systems for health-related purposes, like the calendar app example mentioned earlier, are also included in the scope of this manuscript.

AN ethical challenge can be described with various wordings, mostly referring to a kind of dilemma, problem, or a matter of discussion and disagreement,¹⁵ when a decision is being made which its impacts have moral and ethical dimensions. In this study, these ethical challenges are perceived by the evaluator or researcher who tries to follow the right conduct in the corresponding evaluation or research. However, it can be imagined that these ethical concerns propagate beyond the scope of evaluator or researcher activity, and might be understood by other stakeholders, such as policymakers and the society in general.

:ethical challenge

15: Molewijk et al. 2015

THREE groups of works are out of the scope of this study, and they will not be discussed in this manuscript. We tried to visualize this scoping in an ontology diagram in Figure 11.1, where four categories of ethical challenges in relation to health information systems are depicted, while only ethical challenges in the category **III** are considered for our study. In the first group, respectively I and II in the figure, there are the studies dealing with the ethical issues of using health information systems or of the impact that this usage might create. In the second group, denoted by IV, the studies concern those types of health researches that involve using data collected, communicated, or processed by health information systems. This data can be of type EHR, genomics, biometrics, system usage log files, or any other relevant type, which there might be ethical challenges in recording, storing, using, exposing, aggregating, inferring, and reporting that data. The third group of out the scope studies concern about methods or approaches of implementing ethical assessment for health information systems, with a focus on ethical challenges of types I, II, and IV. Our study positions itself differently and tries to address ethical challenges caused or raised by evaluating or researching health information systems as the subjects of evaluation or research, as denoted by **III** in Figure 11.1.

:what this study is not about

IT is important to note that an ethical issue might be articulated in a way that does not explicitly includes keywords related to ethics. There is a challenge of finding relevant studies and not missing those which their

:ethical topics might be articulated with other terms

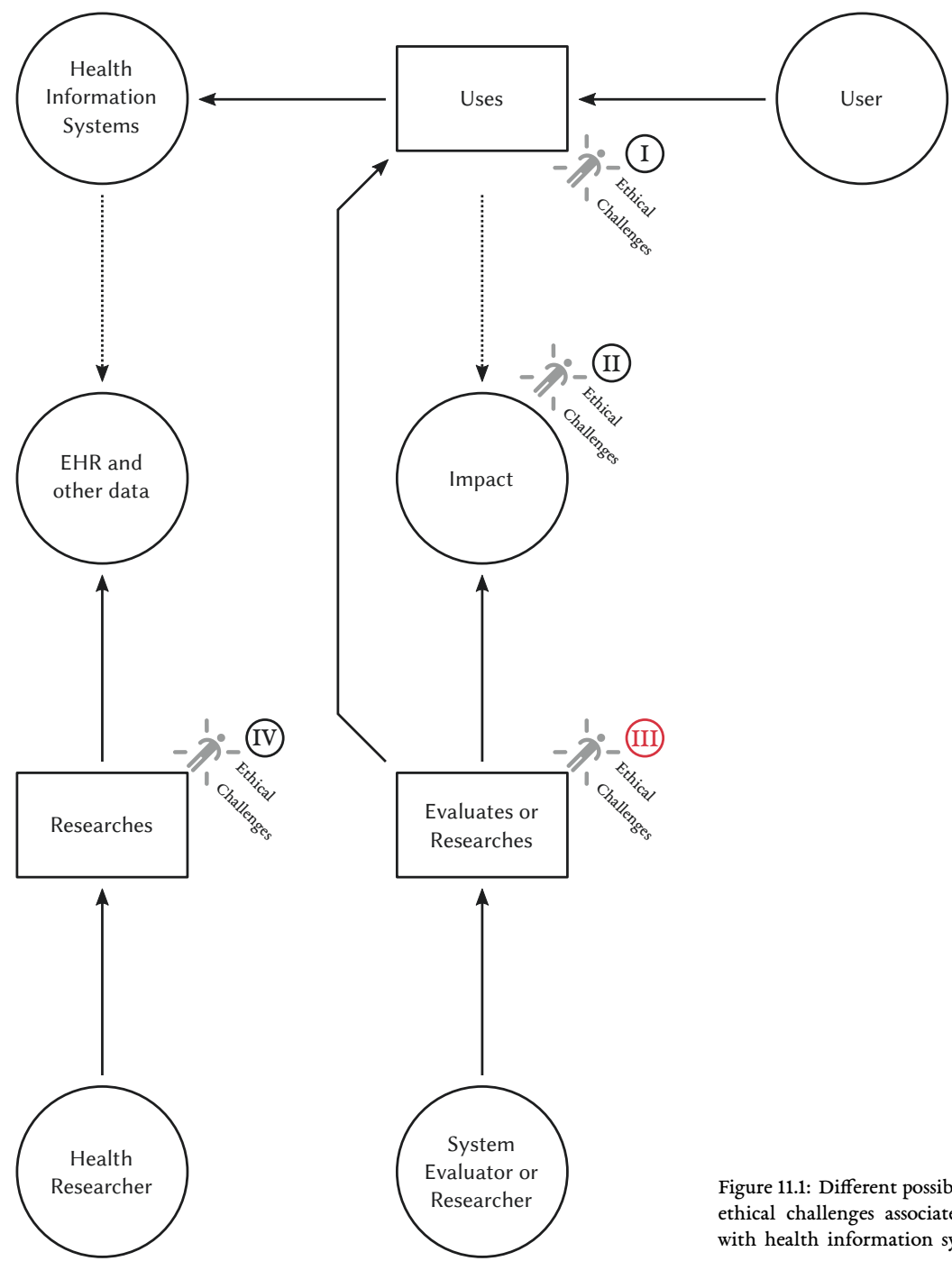


Figure 11.1: Different possible ethical challenges associated with health information systems.

wordings hides them from simple search strategies.

We acknowledge that evaluation and research have similar cores. It is hard, if not impossible, to make a clear boundary between evaluation and research activities. The studies that address research ethics in studying health information systems bear the same intent as those concerning evaluation ethics and should be approached similarly.

IN this manuscript, we are interested in finding the ethical challenges of evaluating or researching health information systems in a systematic approach. Therefore, we devised steps to find those challenges, both through literature review and a systematic postulation. We went through the steps to find a set of ethical challenges and discuss them.

:what we want to do

In the following Section 11.2 section, our method of eliciting the ethical challenges in a specific context, in a systematic approach, is detailed. In the Section 11.3 the result of application of the method, is both presented and depicted. In Section 11.4, those challenges elicited by the method were discussed. The discussion is grouped similar to the proposed evaluation steps in the Section 11.2.

:projection of the steps ahead

11.2 Method and Materials

THIS study takes two approaches to find ethical challenges in the context of evaluating or researching health information systems. In the first approach, a scoping review was performed, framed by the Arksey and O'Malley framework,¹⁶ trying to find the answer to this question: *what ethical challenges have been already identified in the context of evaluating or researching health information systems?* In the second approach, it was assumed there are required qualities associated with the impact of using health information systems that impeding or undermining them due to evaluation or research reasons or side-effects, creates ethical challenges. With this assumption, an approach was designed to elicit those qualities and based on that to postulate ethical challenge cases. The result of both approaches was then situated and combined in a space with the dimensions of evaluation stages, active entities, and quality aspects.

*:two parallel approaches:
scoping review and systematic
postulation*

16: Arksey et al. 2005

The work-flow of the method is depicted in Figure 11.2, which also indicates the number of results in each step. Both approaches are depicted in Figure 11.2, where they are distinguishable by red back-hatched circles and lanes for the scoping review and the blue forward-hatched circles and lanes for the systematic postulation approach. The final result is

compiled in Table 11.4.

11.2.1 Scoping Review

IN the scoping review, with focus on the question: *what ethical challenges are already identified in the context of evaluating or researching health information systems?*, a search strategy was developed and the output search strings were applied in the PubMed, Web of Science, and Scopus databases. The search strategy targets those published works that are constrained by three elements: health information systems, evaluation, and ethics. Only the articles with available abstract content were considered. Each of these databases has different features in searching; for example, we could use Medical Subject Headings (MeSH) keywords for the PubMed but not for the others. Therefore, the search strings are not the same in their scoping.

*:main search constraints:
health information systems,
evaluation, and ethics*

The search strings (Sections 11.A, 11.B and 11.C) reflect the constraint of mandatory inclusion of the above-mentioned three elements. For the *health information system* element, various possible alternatives, such as *health information technology, ehealth, mhealth, telehealth, digital health, medical informatics, health informatics* were considered. Studies that include any of *information technology* or *information and communication technology* terms combined with *health* in their title or abstract were also included. If possible, a combination of MeSH terms and subheadings was used to capture the studies that do not explicitly mention all the required keywords in their abstracts. Although there is a small redundancy for some search terms, redundant parts were kept for the sake of a more clear explanation of how the search strings were constructed. For the *evaluation* element, both the *assessment* and *research* terms were also included in the search strings, required to be either in the title or MeSH terms. It is important to note that although our study focuses on the ethical challenges during the evaluation of health information systems, there is no clear line between researching health information systems and evaluating them, so both were included. For the *ethics* element, it was required that the word *ethic* is mentioned in the study's title or its MeSH terms.

*:main inclusion criterion: only
about ethical challenges due
to evaluating or researching
health information systems*

REGARDING the main inclusion or exclusion criterion, as elaborated in the introduction and Figure 11.1, we are only interested in finding

the ethical challenges that happen due to the evaluation of or research on health information systems. Therefore, the searching results were scanned to exclude those studies that are about ethical issues of using health information technologies, ethical assessment of health information technologies, or the ethics of research in health using information technologies. Though, the studies that refer to the concept of research in a general perspective, i.e., could refer both to the research on health or health information systems, were examined closely to determine which type of research they refer to.

THE final results of the scoping review were analyzed both to elicit the ethical challenges that they mentioned and the major entities (stakeholders and artefacts) that were involved. The ethical challenges elicited in this step were later combined with postulation process results (discussed in Section 11.2.3). The extracted major entities were analyzed and categorized into groups and contexts. These entities were also fed into the postulation process, required for the creation of the three-dimensional space discussed in Section 11.2.2.

:scoping review results

11.2.2 Postulating Ethical Challenges

POSTULATING ethical challenges was performed by assuming that there are required qualities associated with the impact of using health information systems that impeding or undermining them, due to evaluation or research reasons or side-effects, creates ethical challenges. With this assumption, we elicited the ethical challenges by considering three dimensions: the stages of evaluation, the major involving entities (stakeholders and artefacts), and the quality aspects (as the base assumption of the postulation). A visualization of these dimensions is presented in Figure 11.4, a space within which we looked for the ethical challenges by looking at the dimensions and considering combinations of elements from each of them together.

:the three-dimensional space of eliciting ethical challenges

The elements of each dimension (Figure 11.4) is determined by the following approaches (Figure 11.2). In the first dimension, the stages of a typical evaluation were considered by looking at various evaluation studies of the health information system and summarizing them as a series of steps.^{17,18} In the second dimension, the involving entities, stakeholders or artefacts, were determined by investigating the result of the scoping review and also a sample set of health information system cases (to be

17: Nykänen et al. 2011

18: Gremy et al. 1999

discussed later). These entities were grouped as settings and contexts for a better understanding of their role. In the third dimension, the quality aspects were elicited from the same sample set of health information system cases as in the second dimension.

THE sample set of health information systems that was aforementioned is the FI-STAR project and its seven sub-projects. The FI-STAR project was an EU project in e-health, through which seven e-health apps were developed and deployed, each in a member country of the EU.¹ Beyond the general documents of the FI-STAR project,¹⁹ authors of this article have contributed to the evaluation of the project outcomes, through which they have elicited the main quality aspects demanded by the patient or health professional users.²⁰ The Unified eValuation using ONtology (UVON) method² was used for this elicitation of the quality aspects.

Result of applying the UVON method in the FI-STAR project is a list of demanded impact qualities Table 11.2, which we reused them to populate the corresponding dimension (Figure 11.4). Furthermore, the FI-STAR cases were analysed to extract major involving entities, whether artefacts or stakeholders, that can enrich the list of those entities extracted from the scoping review.

The sample cases in the FI-STAR project

19: FI-STAR Consortium
2015

20: Eivazzadeh et al. 2018

20: Eivazzadeh et al. 2018

11.2.3 Combining the Results

THE final result items, whether sourced in the scoping review or the postulation process, are compiled in Table 11.4. Nevertheless, postulation results could overlap with the results from the scoping review; therefore, they might receive the same set of references. Also, regarding that both sets of results reside in the same space (Figure 11.4), it was tried to mention the connection of each item with all three dimensions, if possible.

11.3 Results

THE four stages of a typical evaluation process were considered as *defining the perspective and problematization, running experiments, doing observation, and reporting*.

NINE major entities (stakeholders and artefacts) were elicited, which are visualized in Figure 11.3. The result is grouped into settings and contexts

Quality Aspects
1. Accessibility: if the app is accessible to different users.
2. Adherence: if the patients adhere more to treatment because of the app.
3. Affordability: if the treatment became more affordable for the patient or health care system because of the app.
4. Authenticity: if the information provided by the app is authentic and correct (combined with safety).
5. Availability: if the service provided by the app is available by demand.
6. Efficiency: if the treatment is more efficient because the app was used.
7. Effectiveness: if the treatment process is more effective because the app was used (except for clinical effectiveness).
8. Empowerment: if the app empowers the patient or health professional to know more about their conditions or perform their tasks better.
9. Safety: if the app itself is safe, or makes the treatment process safer.
10. Trustability: if the app improves the trust of the patients in treatment.

Table 11.2: The quality aspects resulting from applying the UVON method to FI-STAR requirement documents. Repeated from the previous study.²⁰

for a better understanding of relations and roles. Stakeholders can be a specific group, such as patients, or a general one such as society. Artefacts can refer to systems, technologies, and embodiments of information (such as documents).

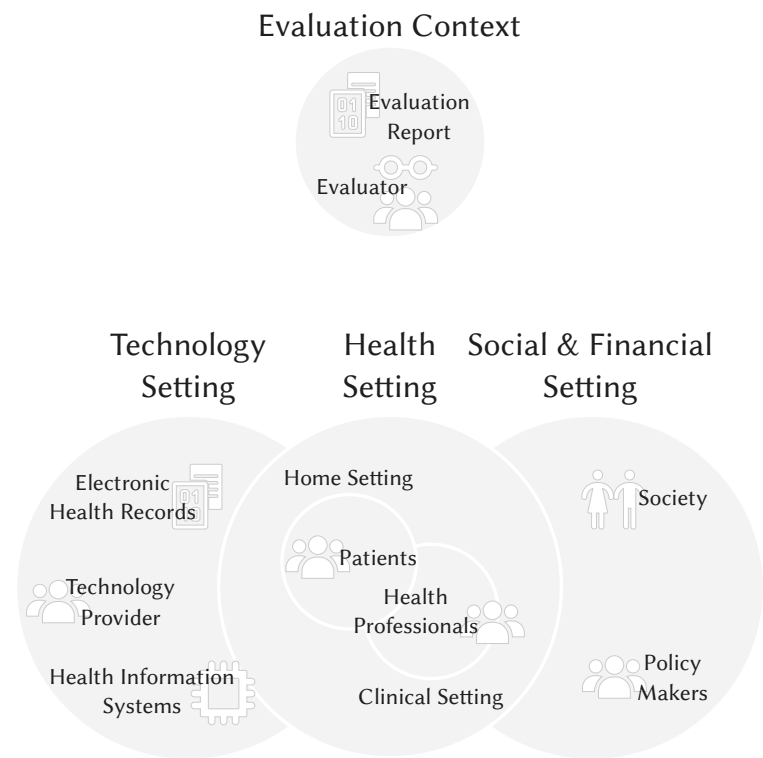


Figure 11.3: Major entities, stakeholders and artefacts, during evaluation of health information system grouped as settings and contexts. ^v

SEARCHING through databases on 26th August 2019 resulted in the following results: PubMed ($N=8/105$), Web of Science ($N=3/22$), Scopus ($N=5/33$). Totally there were 13 distinct studies, out of which 8 were selected, regarding the inclusion and exclusion criterion. The final list of the papers is mentioned in Table 11.3.

Table 11.3: List of articles selected by their title or abstract for the scoping review of the ethical challenges of evaluating health information systems. Further investigation was performed by reading their content, reflected in the *Inclusion* column.

Study: (Author Year), Title	Database ^a			Inclusion ^c
	PubMed	WoS ^b	Scopus	
(Capon et al. 2016), “Realising the Technological Promise of Smartphones in Addiction Research and Treatment” ²¹	+ ^P			●
(Harlow et al. 2019), “Using Participatory Design to Inform the Connected and Open Research Ethics (CORE) Commons” ²²	+ ^P			○
(Lipworth et al. 2017), “Ethics and Epistemology in Big Data Research” ²³	+ ^P			●
(Maar et al. 2010), “Reaching Agreement for an Aboriginal E-Health Research Agenda” ²⁴	+ ^P			○
(Magnusson et al. 2003), “Ethical Issues Arising from a Research, Technology and Development Project to Support Frail Older People and Their Family Carers at Home” ²⁵	+ ^P			●
(Nebeker et al. 2017), “Ethical and Regulatory Challenges of Research Using Pervasive Sensing and Other Emerging Technologies” ²⁶	+ ^P			○ ^d
(Nebeker et al. 2019), “Building the Case for Actionable Ethics in Digital Health Research Supported by Artificial Intelligence” ²⁷	+ ^P	+ ^W		●
(Sokolow et al. 2010), “Confronting and Resolving an Ethical Dilemma Associated with a Practice Based Evaluation Using Observational Methodology of Health Information Technology” ²⁸	+ ^P	+ ^W		●
(Cornford et al. 2001), “Ethical Perspectives in Evaluation of Telehealth” ²⁹		+ ^W	+ ^S	●

continued on the next page.

Table 11.3 – *continued from the previous page*

Study: (Author Year), Title	Database ^a			Inclusion ^c
	PubMed	WoS ^b	Scopus	
(Aitken et al. 2016), “Public Responses to the Sharing and Linkage of Health Data for Research Purposes” ³⁰			+ ^S	●
(Jensen 2016), “Clinical Simulation as an Evaluation Method in Health Informatics” ³¹			+ ^S	○
(Kaplan 2016), “Evaluation of People, Social, and Organizational Issues - Sociotechnical Ethnographic Evaluation” ³²			+ ^S	●
(Nykänen et al. 2016), “Quality of Health IT Evaluations” ³³			+ ^S	○

^a The *Database* column indicates where the article was found by showing a +, superscripted by the first letter of the corresponding database name and located in the corresponding sub-column.

^b Web of Science.

^c A fully-filled circle (●) means the study satisfies the inclusion criteria. A Half-filled circle (◐) means the study discuss ethical challenges in using health information systems but the discussion can be extended to be applied for ethical challenges in evaluation of those systems. An Empty circle (○) means the study does not satisfy the inclusion criteria.

^d Content of the article was not accessible for the authors during the searching stage.

THE stages of evaluation, the major involving entities, and the quality aspect created a three-dimensional space which is visualized in Figure 11.4. The 20 ethical risks and challenges which were found in this space, both through looking at scoping literature review or postulating based on the three dimensions, are summarized in Table 11.4. In the table, each elicited ethical challenge is elaborated with mentioning which stage of evaluation it is more likely to happen, impeding or undermining of which qualities can be associated, and what major entities are involved in the situation. A short note is added for each ethical challenge item, which describes the challenge further by questions or examples.

11.4 Discussion

THE method presented in this study provides a systematic approach for detecting ethical challenges in the evaluation of health information

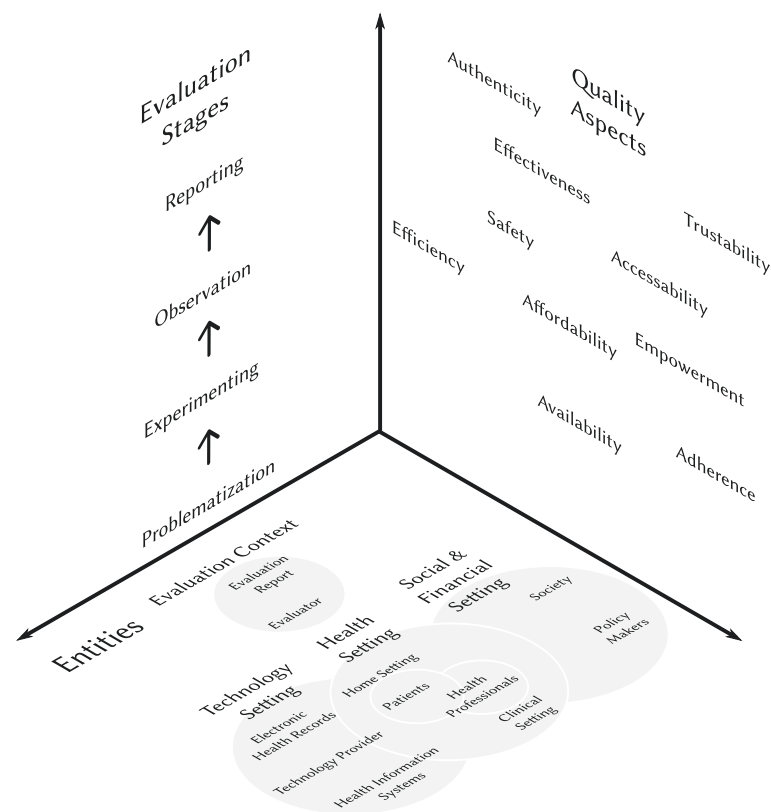


Figure 11.4: The three dimensional space of ethical challenges consisting of evaluation stages, quality aspects, and entities dimensions.

Table 11.4: Possible ethical challenges due to evaluating and researching health information systems. Each ethical challenge is detailed with its associated stages of evaluation, risked qualities, major involving entities (stakeholders, groups of stakeholders, and artefacts), and a short descriptive note.

Risks and Challenges	Stages ^a		Quality Aspects ^b	Major Entities
	P	E O R		
1- Wrong understanding or prioritization of the evaluation goals or values ^{25,29,32}	P	R	<ul style="list-style-type: none"> • effectiveness 	<ul style="list-style-type: none"> • evaluator • policy makers • society
What are the important values for which we are evaluating the health information system?				
2- Ineffectiveness in the research ethics board (REB) functions or misinformed consent due to the nature of technology ^{23,30}	P E		<ul style="list-style-type: none"> • trustability 	<ul style="list-style-type: none"> • patients • entities in the technology setting
Confusing terms of consent or unpredictable outcomes due to the nature of technology, can invalidate the consent.				
3- Misinformed consent due to possible future aggregation of data ^{23,30}	P E		<ul style="list-style-type: none"> • trustability 	<ul style="list-style-type: none"> • patients • entities in the technology setting
<p>Is the subject patient aware of how aggregation of data can identify him/her or his/her condition (leading to privacy or even safety issue)?</p> <p>Can anybody be fully aware of possible contingencies of future aggregation of data?</p>				

continued on the next page.

Table 11.4 – *continued from the previous page.*

Risks and Challenges	Stages ^a	Quality Aspects ^b	Major Entities	
	P	E	O	R
4- Health and safety hazard for patients, due to health information system malfunction ²⁸	E	<ul style="list-style-type: none">• safety	<ul style="list-style-type: none">• patients• entities in the technology setting	<hr/> <p>Could the evaluation or research process make an intervention that cause health information system malfunction, endangering the safety of patients?</p>
5- Health and safety hazard for health professionals, due to health information system malfunction	E	<ul style="list-style-type: none">• safety	<ul style="list-style-type: none">• health professionals• entities in the technology setting	<hr/> <p>Could the evaluation or research process make an intervention that cause health information system malfunction, endangering the safety of health professionals?</p>
6- Disrupting the access to health care service or undermining the patient autonomy ²⁵	E	<ul style="list-style-type: none">• accessibility	<ul style="list-style-type: none">• patients• entities in the health setting	<hr/> <p>Does the evaluation or research process temporarily disrupts the access of patients to health care service? Does it undermine the previous autonomy of patients in accessing to those services?</p>

continued on the next page.

Table 11.4 – *continued from the previous page.*

Risks and Challenges	Stages ^a	Quality Aspects ^b	Major Entities
	P E O R		
7- Disrupting the health care service availability or functionality	E	<ul style="list-style-type: none"> • availability • effectiveness 	<ul style="list-style-type: none"> • patients • health professionals • entities in the health setting • entities in the technology setting
Do we need to disrupt the health care services for the sake of evaluation or research? Does the evaluation or research disrupt the functionality of the technical infrastructure that the health care services rely on?			
8- Discrimination in access to health care service ³⁰	P E O R		<ul style="list-style-type: none"> • patients
Does the approach of evaluation or research make discrimination between subject patients (for the sake of research) in their access to health care service? Does the observation or report advantage a group in terms of the amount of knowledge it provides about them?			
9- Task overload in patients	E	<ul style="list-style-type: none"> • adherence • efficiency 	<ul style="list-style-type: none"> • patients
Does the evaluation or research process overloads the patient with tasks that might affect his/her ability of following and adherence in the main treatment process, or create general inconvenience?			

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Table 11.4 – *continued from the previous page.*

Risks and Challenges	Stages ^a	Quality Aspects ^b	Major Entities	
	P	E	O	R
10- Task overload in health professionals	E	<ul style="list-style-type: none">• efficiency	<ul style="list-style-type: none">• health professionals	
Does the evaluation or research create overload of tasks for health professionals, decreasing their efficiency in providing health care service or creating a general inconvenience?				
11- Usability of the health information system for patients	E	<ul style="list-style-type: none">• safety• effectiveness• empowerment (in patient)	<ul style="list-style-type: none">• patients	
Does the evaluation or research process change the usability of the health information system, making it hard or confusing to follow up the treatment that relies on the system?				
12- Usability of the health information system for health professionals	E	<ul style="list-style-type: none">• efficiency• safety	<ul style="list-style-type: none">• health professionals	
Does the evaluation or research process changes the usability of the health information system, making it hard or confusing to utilize the system to provide health care service?				

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Table 11.4 – *continued from the previous page.*

Risks and Challenges	Stages ^a	Quality Aspects ^b	Major Entities
	P E O R		
13- Escalating cost of health care	E	<ul style="list-style-type: none"> • affordability 	<ul style="list-style-type: none"> • entities in the social and financial setting
Does the evaluation or research increase the total cost of using that health information system in a way that makes it unaffordable or lead us to choose the alternative but less efficient technologies?			
14- Conflict of interests, patient case	E O	<ul style="list-style-type: none"> • empowerment (patient) 	<ul style="list-style-type: none"> • patients • technology providers
Patient, as the receiver of health care service, might express positive but unrealistic attitudes about the health information system, due to the fear of being discriminated in using the system.			
15- Conflict of interests, technology provider case	E O		<ul style="list-style-type: none"> • evaluator • technology providers
Sometimes, the data needed for the evaluation is provided by the same technology provider that has developed and deployed the health information system. The evaluation report might affect the technology provider, creating motivation for tampering the experiment, or observation.			

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Table 11.4 – *continued from the previous page.*

Risks and Challenges	Stages ^a	Quality Aspects ^b	Major Entities
	P	E	
16- Breach of privacy and confidentiality through evaluation report or research results ³⁰	R		<ul style="list-style-type: none">• patients• evaluation report
		Does the evaluation or research report identifies the subject patients and/or their conditions? Is this anonymity affected by future advancements in identification techniques?	
17- Breach of privacy and confidentiality during observation ²¹	O		<ul style="list-style-type: none">• patients• evaluator• entities in the technology setting
		Does the researcher, evaluator, or the third party providing technical logistics can see details about the patients that have not obtained the consent?	
18- Breach of privacy and confidentiality by the patient mistake	E		<ul style="list-style-type: none">• patients• evaluator• entities in the technology setting
		An untrained patient can breach his/her own privacy by misuse of health information system during the experiment period.	

continued on the next page.

Table 11.4 – *continued from the previous page.*

Risks and Challenges	Stages ^a	Quality Aspects ^b	Major Entities
	P E O R		
19- Miscommunication of the risks and challenges ²⁷	R		<ul style="list-style-type: none"> • evaluator • entities in the social and financial setting
Evaluation or research outcomes might be articulated in a way that potential future patients, policymakers, or society in general underestimate or overestimate the risks and challenges of using the system or technology.			
20- Unextendability and uncomparability	R		<ul style="list-style-type: none"> • evaluator • entities in the social and financial setting
Does the evaluation report help prioritizing allocation of scarce resources in health care, increasing the overall benefit of the society?			

^a P → Problemization, E → Experimentation, O → Observation, R → Reporting

^b These quality aspects are elicited from the FI-STAR project, using the UVON method.²

systems. The three-dimensional space of investigation, i.e., entities (stakeholders and artefacts), relevant quality aspects, and evaluation stages, provide a panoptic view of possible ethical challenges that might happen due to running an evaluation process. The method results in finding both general and case-specific ethical situations, reducing the risk of ignoring those situations. Though the method does not guarantee that all possible combinations of entities, aspects, and stages point to a real-world ethical case, nor it enables us to have insight into how each combination

of those dimensions might interact and create a case.

11.4.1 *Ethics of problematization*

WHAT values need to be researched, evaluated, and measured in a health information system (refer to item 1 in Table 11.4)? Evaluators and researchers are supposed to take an objective and neutral approach towards including supportive or unsupportive pieces of evidence when doing an evaluation —albeit with considering the caveats that rise in its possibility and appropriateness.³⁴ Despite this emphasis on neutrality in evidence inclusion, being neutral, open-minded, or receptive to the diversity of values expected from a system is less emphasized. The current trend in the research and evaluation of health information systems focuses on positivistic values such as efficiency, effectiveness, and economic trade-offs³⁵ where the critical-interpretive evaluations are less common.

:values driving the evaluation or research

34: Greenhalgh et al. 2010

35: Kaplan et al. 2008

36: Iserson 2000

In a variety of health information systems, some values might have been sacrificed for the sake of improving some others.³⁶ A project in health information systems is prone to mishandle or undermine this challenging trade-off at the time of problematizing, where the identified problems would drive the whole future of the project. The researcher who runs a summative evaluation of that system might be blinded and biased about other required values if he looks only into the proclaimed targets of the project, ignoring the ethical trade-offs and issues in a bigger context. The real importance of qualities can be another problem in the evaluation process initial perspective. A researcher might base his study on researching and reporting the qualities that their values are not justified, are not a part of the consensus, or are discriminatory. For example, the efficiency of telemedicine solutions might become a compromise for giving up other values, such as social interaction, independence, and autonomy.³⁵ It might decrease the cost of delivering health care service, however, is that able to improve or at least maintain the same level of equity and equality²⁹ or can that create discrimination³⁰ (refer to item 8 in Table 11.4)?

A major conflict in the selection or interpretation of the values in the evaluation of health information systems comes from choosing the side of positivism or interpretivism.^{34,37} While the positivistic norms rule the research in the evaluation arena, there exist critics that accuse this way of evaluation to be mostly a response to our need for stability, simplicity,

37: Greenhalgh et al. 2010

and order rather than the needs of evaluation with the end-users in mind.^{34,38}

38: Kushner 2002

THE ethical challenges of evaluation and researching health information systems can amplify due to the nature of technology. The ultimate impacts of using information technologies are not always known at the time of using them. For example, how a cloud-based solution that stores sensitive information on the cloud can be safe against future threats? This uncertainty creates challenges for a REB when reviewing the proposal of a research or evaluation activity^{23,30} (refer to item 2 in Table 11.4). Similarly, taking consent becomes ethically challenging due to lack of clear image of how the intervention might end up^{23,30,39} (refer to item 3 in Table 11.4).

39: Bauer 2001

11.4.2 Challenges in Experiments

MISSION critical health information systems are not ethically appropriate for invasive evaluation studies. Evaluation research is not supposed to introduce the risk of interruption in service, altering accessibility,²⁵ exclusion of users, discriminating between users, lowering safety standards, or degrading the effectiveness in those systems (refer to items 4,5,6,7, and 8 in Table 11.4). It should be noted that the risk of unsafety can exist both for the patients and health professionals, as the latter group can rely on alarms or instructions produced by the health information system to maintain their safety in the work environment. Care, as an ethical obligation, should be taken when a health information system is going to replace a traditional method or when a newer health information system is going to replace the older one. As examples, more care should be taken when a telemedicine solution tries to replace face to face methods.

:risks of invasive evaluation on critical mission systems

To better understand the required degree of care, one might compare the situation with the medical experiments on individuals. Any medical experiment is associated with a degree of the perceived risk that needs to be revealed when taking consent. Types of experiments exist that always need to be postponed to postmortem —albeit with considerations—such as a biopsy of the brain for diagnosis of Alzheimer; while taking magnetic resonance imaging (MRI) images from the same patient only needs the consent for using the anonymized patient information and brain images for the current or future studies. Health information systems can be critical parts of health care services or health care settings,

and health care service is a determinant of health for individuals.⁴⁰ This means ethical considerations in evaluation or research should be adjusted to the severity of impact when introducing a new health information system, replacing an old one, or manipulating a running one.

40: World Health Organization 2015

A researcher or an evaluator might encounter a situation where he or she discovers a risk for the patients or health professionals due to the malfunction of the health information system. However, any intervention could void the results of research or evaluation.²⁸ This is an ethical challenge for researcher or evaluator as there is a need to assess the degree of possible harm, and if it is real and severe one then to halt the research process—postponing findings that can be similarly important for safety to an unknown future—in the sake of preventing the current existing harm.

:to intervene or not to intervene?

WHEN a health information system is not mission-critical, and its use is voluntarily, then its evaluation can be excused from the previously mentioned restrictions. Many of m-health apps are not core to any mission-critical health service but try to promote a healthier lifestyle. Still, the relaxed constraints in those types of health information systems do not dismiss the need for ethical considerations during the experiment time. Studies that report on the evaluation of health information systems might recruit a large population for the sake of experiment and ask the study subjects to use, alter the use, or stop the use of a system. Any outcome, subtle or more than subtle, might impact lots of people. The risk of low hazard adverse effects increases with a larger population or longer exposure.

:side-effects of non-invasive experiments

As an example, a systematic literature review concludes a small but statistically significant correlation between symptoms of depression and usage of social media in youth population.⁴¹ Another report links using social media with higher anxiety, depression, and poor sleep.⁴² But on the other side, one can find many studies that are characterized by using social media in healthcare, particularly promoting health. The evaluation experiments that increase the risk of those hazards by repeating them through many individuals or exposing the subjects to them for a long term of usage need to take stronger ethical considerations.

41: McCrae et al. 2017

42: Royal Society for Public Health 2017

RESEARCH and evaluation of health information systems can require adding some extra steps in the normal workflow of system utilization

:overload, degradation of the usability, and extra-cost

or the whole health care process. These extra steps, whether added into the user interface of an app or the daily routines of health staff, can both create an overload of tasks for the patients or health professionals and degrade the usability of the system (refer to items 9,19,11, and 12 in Table 11.4). The overload of tasks can not only undermine efficiency for both patients and health professionals, but it also can risk the adherence of the patient to the treatment process. Degraded usability of a health information system might undermine its planned contribution to the health care process, posing a threat to the safety and effectiveness of treatment. It can also reverse the empowerment gains that the system was supposed to provide for the patients.

Evaluations can also be a subject of cost-effectiveness analysis, similar to the technologies. Those extra steps can also increase the cost of the system (refer to item 13 in Table 11.4) in a way that makes it unaffordable, implicitly leading to less efficient or effective alternatives. At the same time, any cost in the limited budgets of health care translates to a trade-off with some health care features. Any extra step in the evaluation should be ethically judged in the light of what needs to be cut for the sake of evaluation. It is also needed to make a balance between predicted benefits of the evaluation from one side and from the other side the possible loss due to the unaffordability of the whole package of the new system and its evaluation.

IN the health sector, animals, instead of human subjects, are used to conduct experiments in the pharmaceutical, surgical, and other medical studies. Even this privilege has been constrained more and more by higher standards for animal rights, requiring sound reasons for permitting any such experiments. But animals are not known to be users of information systems; it is only humans who could play a role in running any of these experiments. The volunteer participation of users is based on an implicit assumption that using those systems does not expose the participant to high risks of hazards. But, it is not always easy to recognize a hazardous quality from a normal or even a valuable one. *:double faceted experiments*

For example, addictive usage is a common, unfavorable, and observable symptom among the users of a variety of software systems. The 10th International Classification of Diseases (ICD) describes habit and impulse disorder, i.e., addiction, in the *F63.8* entry as: “kinds of persistently repeated maladaptive behavior that are not secondary to a recognized psychiatric syndrome, and in which it appears that the patient is repeatedly

failing to resist impulses to carry out the behavior. There is a prodromal period of tension with a feeling of release at the time of the act.”⁴³ Examples can vary from checking emails in unreasonably short intervals to more severe cases of continuously playing computer games. But from the other side, *gamification* and *serious games* are the growing trends in health care, particularly in health information systems. In gamification or serious games, the users go through learning, behavior correction, or creating healthy habits by participating in game-like interaction with those systems.^{44,45} This becomes a question if it is ethical to research addictive behaviors by exposing participants, even voluntarily, and then evaluating the *effectiveness* of that health information system? Examples can be found in the health information systems literature where addictive features of has been suggested as a value for promoting health.⁴⁶

43: World Health Organization 1993

44: Groh 2012

45: McCallum 2012

46: Thorens et al. 2016

Another ethical challenge of experimenting with such addictive usage of health information systems is the normative tone in reporting the result of the research. For example, improving *adherence* is considered a favorable quality aspect in some types of health information systems.² But adhering to something can considerably indicate or connote being addicted to that thing. Studies that report the evaluation of health information systems from the adherence angle, if possible, might need to weigh and be more specific on the type of adherence being observed.

INFORMED consent is an integral part of medical experiments and trials. The volunteer subjects explicitly express that they are well informed about the process of the experiment and its possible consequences and that with these considerations, they pursue going through the experiment. In some circumstances, such as telehealth, the informedness does not come easily as the risks of the new health information technology are not clear at the time of trial^{23,30,39} (refer to item 3 in Table 11.4). Regarding that only the humans, but not animals, can be subjects of information technology experiments, there is no prior knowledge of possible adverse effects of those technologies. When health information systems are core to a health care setting and might interact with the subjects, being informed about experiments requires continuously providing education about possible benefits and burdens of the information technologies to the subjects of the study.³⁵

:informed consent

PROTECTING confidentiality and anonymity of health information on individuals is the responsibility of the experimenting entity. Still,

:the responsibility of training against the wrong usage

the constraint does not apply to the subjects themselves. While the experimenting entity is supposed to provide a secured infrastructure and trained personnel, but an untrained subject can unintentionally breach his privacy by the wrong use of the experiment technologies (refer to item 18 in Table 11.4). This situation raises the question that to what extent the researchers are ethically responsible for training experiment subjects of a health information system to protect themselves against unintended self-induced consequences, such as deanonymization.

11.4.3 Challenges in Observation

THE approach in big data and data analytics contrasts with other forms of user feedback collection in the sense that user consent in providing information is not taken in explicit terms (refer to items 3 and 16 in Table 11.4). While in a typical user feedback gathering, such as when using questionnaires and interviews, the user is well aware of what kind of information he provides to the data gatherer, but that is not the case in big data and data analytics.²³ In big data and data analytics, there is usually a clear set of data features being collected, but they can be combined in indefinite and undefined forms. Usually, in this situation, only a general consent is taken that authorizes the analyzer entity to collect categories of information and be able to combine them in arbitrary ways to draw conclusions that might be loosely bounded by general terms, such as *research goals*. Even if the anonymity of study subjects are protected in the final research or evaluation report, however, most of the time, it is not clear how researchers, health professionals, technical staff, and third-parties are restricted²¹ from identifying the subjects beyond the privileges confirmed in the consent (refer to item 17 in Table 11.4).. Browsing the privacy policy agreements of well-known information technology companies,^{47–49} one might not be sure how the goals of *service the user* might be defined. In the evaluation of health information systems, we might need to be more transparent and precise when communicating with the subjects the types of results or the degree of flexibility they might need in the future for combining the gathered data.³⁰

:the vagueness of consent in big data and data analytics

47: Facebook Inc. 2016

48: Google Inc 2017

49: Apple Inc. 2016

PRACTICALITIES of research and evaluation of health information systems might force the researcher to conduct his research by relying on pieces of information, such as application logs, that are only provided by the developers and implementors of those systems (refer to item 15

:conflict of interests between the patient, health professional, and technology provider

in Table 11.4). Also, sometimes, the developers of the system are the only ones who have the required logistics to access the end-users, and the researcher or evaluator has to recruit them as a proxy towards the end-users, patients or health professionals. Developers, implementors, and owners of a health information systems are the beneficiaries in the final assessment, at the same time, they have exclusive access to some of the tools and materials required for the research. This, of course, is a conflict of interests that might endanger the objectivity⁵⁰ of the research. The nature of this deviation from objectivity can be suppression of the results that do not confirm the required quality for the system, hiding adverse or unfavorable events caused by using the system, and mishandling of the research protocol as it is ratified by the corresponding ethical committee if any.⁵¹

50: Shamoo et al. 2009

51: Shah 2011

In a similar case, the asymmetrical power relation between patient and the person who performs the evaluation query, which could be health professional or technology provider, can force the patient to express positive assessment (refer to item 14 Table 11.4). This can be due to the interpersonal relationship or even the fear of being discriminated in receiving health care or using the system if a none-positive attitude is expressed.

Normally, reporting those possible leakages of objectivity is required—although postmortem—counteraction against those risks. Still, with some planning, systems can be developed to be friendly for more neutral evaluations, where the required data acquisition mechanisms for objective research are embedded in the software, its deployment processes, and maintenance services. Independent feedback collection platforms can be examples of such technical tools for ethical research and evaluation.

:comparable evaluation results

52: Eslami Andargoli et al. 2017

53: Banta 2003

11.4.4 Challenges in Reporting Results

HEALTH technology assessment and evaluation of health information systems are both tools for policymakers to analyze the policies and make the right decisions^{52,53}. Indicators, such as *quality-adjusted life year (QALY)* and *disability-adjusted life year (DALY)*, have been introduced to enable measuring and comparing the impact of health interventions and technologies. It is tough for the evaluators of health information systems to use such indicators to report on the impact of health information systems,⁵⁴ in particular, if the impact of health information technologies on the health care is not well-vetted yet.⁵⁵

Here, I distinguished between *technology* and *systems*. The first one is not specific to instances but more focused on a particular technology. The latter is specific to one or more instances but might be composed of many technologies.

54: Eivazzadeh 2015

55: Chaudhry et al. 2006

The limitation of research in the evaluation of health information systems in recruiting clinical indicators, such as QALY and DALY, creates an ethical inefficacy when different options of investment in health information systems exist but the evaluation results cannot be compared to each other to help to select the best choice (refer to item 20 in Table 11.4). Different investment and development options could create different clinical impacts. In the absence of sound indicators, similar to QALY and DALY, there is an ethical obligation for researchers to produce evaluation reports that are *comparable* as much as possible. Methods of evaluation that facilitate the comparison of heterogeneous health information systems² are desirable in this regard.

RESEARCHERS are usually supposed to publicly publish their data findings with the finest resolution, as much as it makes the results reviewable and the experiments repeatable, while avoiding the breach of privacy and confidentiality. At the same time, the public publication of data can make it possible to deanonymize the individuals^{30,56,57} (refer to items 15 and 16 in Table 11.4). This creates an ethical challenge, in particular, considering that researchers cannot anticipate whether the future data or methods would make deanonymization possible or not. The right trade-off between revealing and censorship approaches, or between aggregated and detailed data, becomes an ethical burden which can only be reduced, but not removed, by following the relevant regulations.

:*aggregated data*

56: Sweeney 1997

57: Nematzadeh et al. 2010

EVALUATION of research outcomes might be articulated in a way that potential future patients, policymakers, or society in general underestimate or overestimate the risks and challenges of using the system or technology²⁷ (refer to item 19 in Table 11.4). Reporting the evaluation or research output without understanding the context of consumption of that report can not only undermine the report added value, but it can also contribute negatively to the public understanding of the health information systems and technologies, delaying their right utilization.

:*miscommunication of the risks and challenges.*

11.4.5 *The Method, Feature and Limits*

THERE are limits concerning both approaches to the method used in this study. In the scoping review, we have limited ability to find the articles that are about ethical issues, by just specifying the right keywords. Therefore, it can be imagined that there exist studies about ethical chal-

:*limits*

lenges that have not explicitly used a keyword like *ethics* in their titles or abstracts. This is an intrinsic issue with the category of review study; however, we had a piece of evidence for the issue. The number of articles found in the PubMed database was relatively three to five times more than Sopus and Web of Science. However, excluding the MeSH terms, will drastically drop the number of results from PubMed (N=44), making it similar to the results from the two other databases. This shows that there are articles which could not be captured by normal keywords; however, their authors have categorized them in the ethics group, using the relevant MeSH terms.

The limit with the postulation approach is the width of the qualities resulted from applying the UVON method in the FI-STAR project. One can imagine that more qualities might be elicited if the UVON method was applied over a greater number of health information systems, a greater number of users, or it was configured to make less unification among similar qualities.

THE method used in this study has the capacity to be reused in similar future studies. In similar studies, again, a three-dimensional space (Figure 11.4), consisting of stages of the main process, demanded qualities and acting entities dimensions, can be reconstructed to find the possible ethical challenges. The idea behind the approach of using three-dimensional space is that it becomes easier to identify an ethical challenge by specifying when it happens (stages), who or what is involved (entities), and what important thing can be missed (quality aspects). *:reusing the method*

As performed in this study, the stages of the main process can be extracted from the literature; the involving entities can be elicited both from literature and sample cases; and the quality aspects can be elicited and organized from sample cases by a method, such as UVON. Then, one can run a round-trip of locating known challenges in the space and postulating further challenges by looking at the elements of each three-dimension together.

11.5 Conclusion

IN this study, we focused on ethical challenges that can be caused or raise due to evaluating or researching health information systems. We distinguished this category of ethical challenges from other categories of ethical challenges that can happen in the context of using health information

systems. Through a systematic method comprising of scoping review and postulation, we discovered a list of 20 possible ethical challenges.

The items in the list were discussed through the four stages of problematization, experimenting, observation, and reporting. The discussion denotes issues such as the actual value of evaluation, breach of privacy, risks for safety, problems with usability and accessibility, conflict of interests, problems with the informed consent, and miscommunication.

The systematic method introduced in this study, recruits both scoping review and postulation approaches, and considers a three-dimensional space, comprised of evaluation stages, quality aspects, and acting entities dimensions. This space can be reconstructed in similar studies, for eliciting ethical challenges in the subject context.

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Appendices

11.A Search String for PubMed

```

1      (
2      "Evaluation Studies as Topic"[MeSH Term]
3      OR
4      "Technology Assessment, Biomedical"[MeSH Terms]
5      OR
6      evaluati*[Title]
7      OR
8      research*[Title]
9      OR
10     assess*[Title]
11    )
12  AND
13  (
14  (
15  (
16  "Telemedicine/ethics"[MeSH Term]
17  OR
18  "Information Systems/ethics"[MeSH Term]
19  )
20  )
21  OR
22  (
23  (
24  "health information technology"[Title/Abstract]
25  OR

```

```

26      "health information technologies"[Title/Abstract]
27  OR
28      "health information system"[Title/Abstract]
29  OR
30      "health information systems"[Title/Abstract]
31  OR
32      ehealth*[Title/Abstract]
33  OR
34      mhealth*[Title/Abstract]
35  OR
36      telehealth*[Title/Abstract]
37  OR
38      "digital health"[Title/Abstract]
39  OR
40      "medical informatics"[Title/Abstract]
41  OR
42      "health informatics"[Title/Abstract]
43  OR
44      (
45          "information and communication technology"[Title/Abstract]
46      AND
47          health[Title/Abstract]
48      )
49  OR
50      (
51          "information technology"[Title/Abstract]
52      AND
53          health[Title/Abstract]
54      )
55  )
56  AND
57      (
58          "Ethics"[MeSH Term]
59      OR
60          ethic*[Title]
61      )
62  )
63  )
64

```

11.B *Search String for Web of Science*

```

1  (
2  (
3      TI=evaluat*
4  OR

```

```

5      TI=research*
6  OR
7      TI=assess*
8  )
9  AND
10 (
11 (
12     TS="health information technolog*"
13 OR
14     TS="health information system*"
15 OR
16     TS=ehealth*
17 OR
18     TS=mhealth*
19 OR
20     TS=telehealth*
21 OR
22     TS="digital health"
23 OR
24     TS="medical informatics"
25 OR
26     TS="health informatics"
27 OR
28     TI=
29     (
30         "information and communication technolog*"
31 AND
32     health
33     )
34 OR
35     TI=
36     (
37         "information technolog*"
38 AND
39     health
40     )
41 )
42 AND
43 (
44     WC=Ethics
45 OR
46     WC="Medical Ethics"
47 OR
48     TI=ethic*
49 )
50 )
51

```

11.C Search String for Scopus

```

1  (
2  TITLE(evaluati*)
3  OR
4  TITLE(research*)
5  OR
6  TITLE(assess*)
7  )
8  AND
9  (
10 (
11 (
12 TITLE-ABS-KEY("health information technolog*" )
13 OR
14 TITLE-ABS-KEY("health information system*" )
15 OR
16 TITLE-ABS-KEY(ehealth*)
17 OR
18 TITLE-ABS-KEY(mhealth*)
19 OR
20 TITLE-ABS-KEY(telehealth*)
21 OR
22 TITLE-ABS-KEY("digital health")
23 OR
24 TITLE-ABS-KEY("medical informatics")
25 OR
26 TITLE-ABS-KEY("health informatics")
27 OR
28 (
29 TITLE-ABS-KEY("information and communication technolog*")
30 AND
31 TITLE-ABS-KEY(health)
32 )
33 OR
34 (
35 TITLE-ABS-KEY("information technolog*")
36 AND TITLE-ABS-KEY(health)
37 )
38 )
39 AND
40 (
41 SRCTITLE(ethic*)
42 )
43 )
44

```

Design of a Semi-Automated and Continuous Evaluation System

Customised for the application in e-Health

SHAHRYAR EIVAZZADEH, MARKUS FIEDLER, JOHAN S. BERGLUND,
PETER ANDERBERG, TOBIAS C. LARSSON

Abstract

Background and Objectives The survey-based evaluation of a system, such as measuring user's satisfaction or patient-reported outcomes, entails a set of burdens that limits the feasibility, frequency, extendability, and continuity of the evaluation. Automating the evaluation process, that is reducing the burden of evaluators in questionnaire curation or minimising the need for explicit user attention when collecting their attitudes, can make the evaluation more feasible, repeatable, extendible, continuous, and even flexible for improvement. An automated evaluation process can be enhanced to include features, such as the ability to handle heterogeneity in evaluation cases. Here, we represent the design of a system that makes it possible to have a semi-automated evaluation system. The design is presented and partially implemented in the context of health information systems, but it can be applied to other contexts of information system usages.

Method The system was divided into four components. We

followed a design research methodology to design the system where each component reached a certain level of maturity. Already implemented and validated methods from previous studies were embedded within components, while they were extended with improved automation proposals or new features.

Results A system was designed comprising four major components: *Evaluation Aspects Elicitation*, *User Survey*, *Benchmark Path Model*, and *Alternative Metrics Replacement*. All components have the essential maturity of identifying the problem, identifying solution objectives, and the overall design. In the overall design, the primary flow, process entities, data entities, and events for each component are identified and illustrated. Parts of some components have been already verified and demonstrated in real-world cases.

Conclusion A system can be developed to minimise the human burden, both for the evaluators and respondents, in survey-based evaluation. This system automates finding items to evaluate, creating questionnaire based on those items, surveying users' attitudes about those items, modelling the relationships between evaluation items, and incrementally changing the model to rely on automatically collected metrics, usually implicit indicators, collected from users, instead of requiring the explicit expression of their attitudes. The system provides the possibility of minimal human burden, frequent repetition, continuity and real-time reporting, incremental upgrades regarding environmental changes, proper handling of heterogeneity, and a higher degree of objectivity.

Keywords

Evaluation, Questionnaire, Information Systems, Patient Reported Outcome, User's Attitude, Automation

12.1 Introduction

SURVEYING, a traditional and well-established way of evaluating systems, is the most common approach when users' attitudes about the outcomes of a system are required. By surveying, a subjective evaluation of the system by its users becomes possible, when the objective evaluation is not feasible or preferred. For example, in health care, using patient reported outcome measures (PROMs) is common for evaluating interventions, with both that intervention which creates clear health outcomes and the one which it is hard to associate with any direct health impact. This approach also applies to the evaluation of an intervention that introduces a technology or a system into a health setting. For a health information system intervention, which is usually facing the challenge of associating clear clinically approved health outcomes to their usage, questionnaires are the central measurement instrument in evaluation.

1: Blessing et al. 2009

In this manuscript, we follow a design research approach¹ to identify the problems with evaluating a system outcome by surveying users with questionnaires and devising a solution, a design, that can overcome those problems. We have contextualised our design for the evaluation of health information systems, and parts of it already have been developed and examined in this context. However, the proposed design is not limited to health information systems. It can be used to evaluate any system in which the overall attitude of its user is core to the definition of success, a continuous evaluation is required, and a great deal of budget and human resources for evaluation is not feasible.

12.2 Problem Identification

IN evaluating interventions, especially in summative form, a common approach is surveying users, for example the patient or health professional users of health information systems. Users give a holistic account of an intervention, though it is limited to the aspects specified in the questionnaire. However, there are inherent challenges with evaluations using surveys, both in the creation of questionnaires and survey implementation.

AN initial challenge for a user-centric evaluation is to determine what aspects to evaluate. Users and experts both have the authenticity to identify evaluation aspects. Experts usually express their opinions through *what to evaluate?*

evaluation frameworks that specify aspects that need assessment. An evaluation framework is not case-specific; it advises evaluation aspects statically and universally. Conversely, the users of a system can demand outcome qualities that simultaneously determine evaluation aspects. These demands on specific qualities are case-specific and cannot be extended directly to other cases. We can rearticulate these two approaches as top-down or bottom-up approaches. In the top-down approach, an existing and relevant evaluation framework suggests what to evaluate, and the suggestion needs to get contextualised in the case. In the bottom-up approach, the evaluation aspects are elicited from the users or other stakeholders, but need to be curated and integrated.

However, being dynamic or context-specific means that one must review and update evaluation aspects whenever users demand new features, qualities, or outcomes, as well as when the stakeholder or users' population changes and the new population has different members or reflects new perceptions.

COMPARING two or more systems can be a requirement for an evaluation task; however, there is a caveat to such a demand. Subject systems can be heterogeneous to a large degree, making it challenging to find or define the commonalities that enable comparisons. To handle the comparison task, one must elicit systems' commonalities. However, those commonalities should not be too generic to be common among many other irrelevant systems. *:heterogeneity*

A similar problem arises with a heterogeneous set of systems when trying to evaluate the whole set. The answer to 'What should we evaluate?' can be more challenging if there is more than one system for evaluation or a system is composed of several distinct parts, where there are different aspects to evaluate for each. In other words, if a set of systems or parts of a single system construct a heterogeneous set of items there would be challenges in finding aspects to evaluate, because the result of evaluating those aspects in all systems must be added and summarised. An extended answer should address the heterogeneity of evaluation aspects and find a common denominator for different systems, so results can be added and combined. *:cost of survey*

THE evaluation of health information systems can place a high demand on individual, organisational, and financial resources, including but not limited to evaluators' labour, user attention, or disruptions in treatment. *:(full) automated vs. semi-automated*

Automation can help reduce the pressure on those resources by replacing human agents with software. But many of the evaluator tasks cannot easily be delegated to machines. The same is true and, indeed, a greater challenge where users' attitudes are required. The first impression is that one cannot collect users' attitudes without their involvement and intentional interaction, which increases the challenge of the evaluation. Regarding the above mentioned practical limitations, a more realistic goal might be to consider a scale of automation from semi to fully automated. The semi-automated situation can be defined as a state in which a considerable human burden has been eliminated from the evaluation tasks but there still are points at which human judgement, engagement, or intervention is required. For the fully automated, or simply called automated situation, it can be defined as a state in which the need for human intervention and judgment has been minimised to infrequent and sporadic cases of monitoring or decision making.

THE explicit expression of users' attitudes about the impact of a system, that is the subjective attitude, has both advantageous and disadvantageous sides. The advantage is that user-reported outcomes, such as PROM, constitute a holistic approach to evaluate the system. It avoids the pitfall of reductionism in investigating problems and the benefits of a system by objective approaches, such as measuring some objective measures.² The disadvantage is that users' attitudes might be influenced by factors like the relationship with the evaluator or developers of the system, which are out of the scope and intentions of evaluation. An approach is demanded that can find the right combination of these two approaches and make a good tradeoff.

2: Greenhalgh et al. 2010

Automated metrics can be considered a solution to the aforementioned problems. We can define the automated metrics as those mostly implicit indicators that are measured by observing users' behaviour (such as their navigation pattern through web pages) which do not require their intentional and conscious interaction, while, they are proxies to their intentions. However, automated metrics are usually semantically dumb compared to surveys. For example, the actual usage of a health information system can be monitored easily by the relevant analytical indicators, for instance system logs, but it is very hard to correctly discern the degree of user satisfaction.

*:automatically collected metrics
(automated metrics)*

:updated evaluation

PERIODICAL surveys using questionnaires might capture users' at-

titudes about a health information system in snapshots, but they are expensive and time consuming for regular repetition. Due to changes in the context, users, or technologies, those surveys, if not updated, might become less relevant in pointing to the most important qualities that create satisfaction.

IT is hard to repeat non-automated evaluations, due to the need for users' direct involvement. For the same reason, it is very hard if not impossible, to run the evaluation continuously. Regarding the cost structure of evaluations, unspecific items can be reused in the proceeding turns, but other items create the same expense each time. An already well-designed questionnaire can be reused as long as it is relevant, and new items do not need to be considered. However, running the actual survey repeats its costs and burdens. Each instance of running a survey requires almost the same amount of human labour as before. *:continuous evaluation*

Moreover, a real-time, continuous evaluation is reflective. For user-reported outcome measures, a continuous evaluation shows trends or even drastic changes in the attitudes and perceptions of users. Instead of guessing the right time to rerun the evaluation, the continuous evaluation sends an alarm when there is a change.

As a designed product, health information systems in their lifespans go through iterations of design and redesign for the sake of incremental improvements or disruptive innovations. Continuous evaluation enables designers to sense a user's reaction in real-time, creating a feedback loop to design decisions.

MISSION critical health information systems must be reliable. Therefore, they are monitored for their functionality. Beyond the functionality, the status of how those systems are accepted or adopted and if the users are still satisfied with them can change. However, to the best of our knowledge, less attention has been paid to this perspective. Here, the question is not only if users are utilising those systems less or more, but also if they are drifting away from satisfaction with the system. It can be informative and enlightening for designers, managers, or even end users to understand the reason for a churn rate or what is impacting any increase or decrease in acceptance and satisfaction. To reach this enlightenment, one must align and compare those increases or declines with other events and trends at the setting, enterprise, or societal level to estimate what might be the impacting factors. Reaching this enlightenment *:real-time monitoring*

probably demands vast effort, while even smaller-scale investigations might be still rewarding, facilitate those investigations, and be appreciated.

12.3 Objectives of the Solution

PROVIDING the possibility of automated or semi-automated, continuous, dynamic, and analytical evaluation is the main objective of the solution provided in this study. All these required four features are in the context of summative evaluation. In addition, the solution is intended to be used for only the type of evaluations based on user-reported outcome assessments or other measurements that are related to, perform as a proxy, or closely follow user-reported assessments of the outcome.

THE feature of automation is dispersed across the whole functionality of the solution, requiring the least possible interaction from the evaluator or users of the health information system. Most notably, automation should find the answer to 'What to evaluate?' by referring to user-requested qualities or evaluation aspects specified in an arbitrary evaluation framework. Additionally, when there is more than one way of combining measurements to evaluate the health information system, the solution should automatically provide possible valid combinations and calculate the possible comparative indicators between options. Fitting a model to available data and other types of calculations should be seamless. As an automated evaluation solution, instead of the pulling approach whereby the user actively monitors the situation, the solution should be able to push notifications and automatically alert evaluators about noticeable changes in evaluation results or conditions. *:aspects of automation*

Automatic ontology generation has long been a research topic.^{3,4} 3: Noy et al. 2000
However, the automatic or semi-automatic generation of questionnaires that reflect users' most-demanded impact qualities needs more components than the automatic creation of ontologies. This automated generation of questionnaires can be more complicated if, for example it is to be used in a model, there should be groups of questions, each representing one concept. 4: Arabshian et al. 2012

THE solution should continuously track changes in the user's perception of evaluation dimensions. By being continuous, it means the evaluation is non-interrupted, operates for the lifespan of the subject health infor- *:continuous*

mation system, and needs few to none repeating queries from users. In other words, tracking changes in users' perceptions should not need us to repeat the burden of directly querying the users by questionnaires; instead, it should find other equivalent and automatically collectible indicators that can replace the items in the questionnaire. Being an equivalent indicator means new measurements should mimic user-reported assessments as closely as possible. Nevertheless, there are always constraints to this flexibility, be they the maximum theoretically possible flexibility in replacing measurements and their relationships with other alternatives, or practical limitations in leeways due to solution specifications.

Continuity is considered important to the evaluation of health information technologies, especially if those systems or technologies are evolving.⁵ However, to the best of our knowledge, the method of implementing an automated continuity is not described in the literature. Nonetheless, the functionality of some systems, such as recommender systems in e-commerce,⁶ might be considered some sort of automated prediction of user evaluation, where the automation characteristic also makes it possible to be continuous. Nevertheless, the breadth of evaluation needed for health information systems differs from recommender systems, as does the nature of their continuous evaluation.

5: Mohr et al. 2013

6: Schafer et al. 2001

THE solution should provide the possibility of dynamic evaluation. By being dynamic in evaluation, we mean the solution can be reconfigured to receive various sets of measurements or rely on disparate assumptions in modelling the relationships between measurements, while its evaluation remains valid in the range that it is possible regarding the changes.

The need for a dynamic or adaptive evaluation approach for information systems is already identified, especially for the changing contexts⁷ or goals.⁸ Meanwhile, studies on adaptive systems and user modelling⁹ can be extended to applications in the evaluation of health information systems. We could not find any study that explored the automation or minimisation of the human burden in an adaptive and user-centred evaluation of information systems.

7: Sherwood et al. 2009

8: Lindgren et al. 2016

9: Kobsa 2001

AUTOMATED metrics are forms of user feedback that require no interaction from the user side. Measuring automated metrics, compared to running surveys, usually requires less human resources. They are forms of user feedback that need no interaction from the user side. This

:automated metrics

interactionless trait lets other features come to the scene. Automated metrics can be measured in assorted temporal scales, and they can be continuously collected because they do not demand bandwidth from the users' limited channel of attention.

The solution should make a combination of analytical evaluation¹⁰ benefits (i.e. automated metrics) alongside the interpretive evaluation. That means user-reported outcome assessments should be the core of the solution output, while the analytical evaluation, that is relying on automated metrics, should be provided as much as it closely follows user-reported assessments of the outcomes.

There are already attempts to combine users' opinions and implicit automated metrics. For example, hybrid recommender systems in online shops base their recommendations on combining explicit expressions of users' opinions, such as ratings, and implicit automated metrics, such as page views.^{11,12} However, recommender systems usually focus on the specific field of users' interests in products, which is much narrower than the vast area of the evaluation of impact qualities. In addition, those systems usually aggregate users' opinions with the implicit automated metric, but they have less intention to replace surveys with those metrics. Some health information system studies have used automated metrics, such as web analytics, with user-reported methods. Nevertheless, they have used it alone,¹³ complementing user-reported data,¹⁴ or running in parallel.¹⁵ To the best of our knowledge, no study on a health information system has tried to replace users' opinions with automatic metrics in an evaluation process. Furthermore, though with a less rigorous search, we could not find any study in other disciplines that performs a replacement for the sake of lower costs, higher objectivity, or other relevant reasons.

10: Stone 1990

11: Zanker et al. 2009

12: Manzato et al. 2015

13: Wu 2018

14: Ortega-Morán et al. 2017

15: Tell et al. 2018

12.4 Design and Development

WE have considered four components to our system, each with distinct functionality. The overall architecture of the system is demonstrated in Figure 12.1. Respectively, details of blocks are depicted in Figures 12.2, 12.3, 12.4 and 12.5, using Business Process Model and Notation (BPMN). To keep the figures simple and easy to read, we omitted loops and variations of tasks from the figures, instead explaining them through the manuscript.

Component 1 combines *User-Requested Outcome Qualities*, which can be embedded in unstructured text pieces, with an *External Evalua-*

tion Framework to create a questionnaire. Component 2 runs a survey based on the questionnaire. Component 3 creates a *Benchmark Model*, a path model, from the items in the questionnaire and calculates relationships based on questionnaire results. The overall structure of the path model is borrowed from an archetype in the database of *Path Model Archetypes*. Component 4 replaces some variables of the path model with automatically sensed variables, that is automated metrics, while keeping the overall performance of the model. The automated metrics belong to a database of metrics called *Pool Of Automated Metrics*, which stores various automatically measured metrics for the users as data time series, like application log files.

Through discussing the design and development of the system, we consider two distinct groups of users. The first group is the end users of the to-be-evaluated health information system that we simply call users; the latter group employs the automated evaluation system, we call them evaluators to distinguish them from the first group. For the sake of brevity, when we want to refer to user-requested outcome quality, framework-specified outcome quality, or a combination of both, we only use the term *quality*.

12.4.1 Creating Questionnaire

THE first component of the system, as shown in Figure 12.2, creates a questionnaire in four steps. First, it identifies the qualities that are required to be evaluated by users. Second, it optionally extracts qualities from an evaluation framework, and third, it creates an ontology from the qualities of both sources. Fourth, it creates a questionnaire for the ontology for collecting users' feedback. Details of this component functioning are explained in the Unified eValuation using ONtology (UVON) method, explained in the publication.¹⁶

16: Eivazzadeh et al. 2016

Two sources are considered for the elicitation of qualities. Users are the first and mandatory source, into which the evaluation aspects suggested by an evaluation framework can optionally merge. In Figure 12.2, the user source is labelled *User-Requested Outcome Qualities*; the other source is labeled *External Evaluation Framework*.

An evaluation framework can complement user-specified requirements. The qualities required by users are collected in a bottom-up approach, while evaluation frameworks, usually the embodiments of experts' opinions, specify the evaluation aspect, that is qualities, through

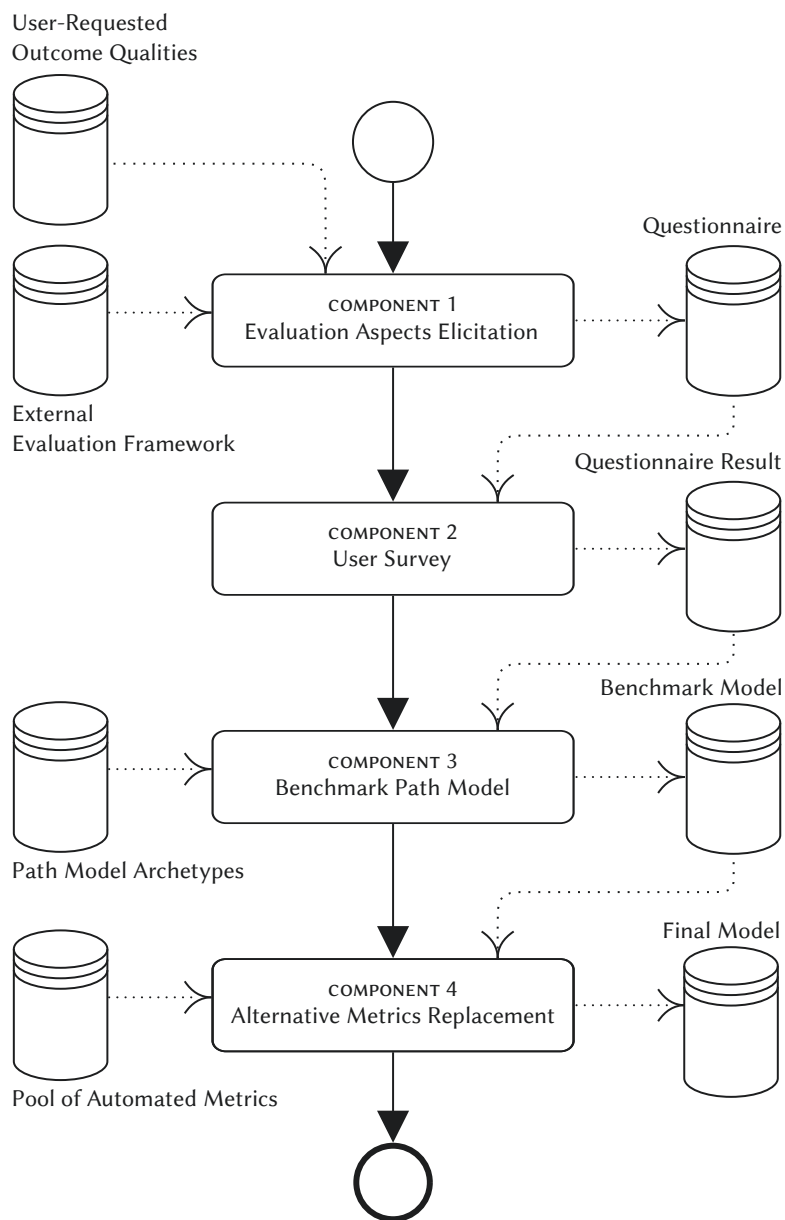


Figure 12.1: Overview of the evaluation system's architecture, showing input data objects on the left, components in the middle, and output data objects on the right column.

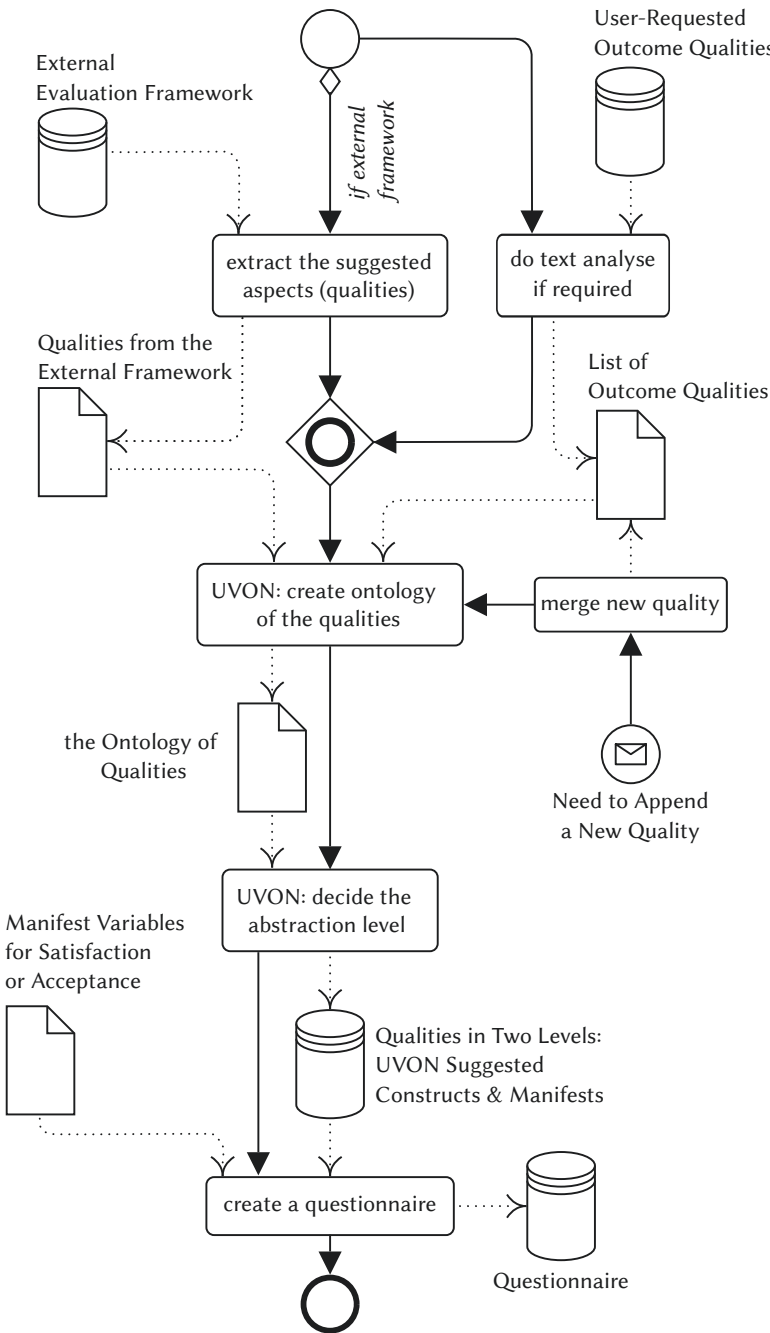


Figure 12.2: Evaluation Aspects Elicitation component: Finds evaluation aspects and creates the corresponding questionnaire.

the top-down approach. Nevertheless, the outputs of these two approaches can differ, while both are valid. In addition, user-required qualities are case-specific, while the qualities specified by the evaluation framework are universal for a class of cases. Combining these two sets of qualities gives better coverage of possibly relevant evaluation aspects.

Eliciting qualities from *User-Requested Outcome Qualities* can be both manual or automated. The automatic extraction of requirements by natural language processing techniques has a long history in software engineering;¹⁷ still developing through the utilisation of text summarisation methods that use human language technologies.^{18–20} There is less need for automation in eliciting evaluation aspects from evaluation frameworks. They are usually explicitly expressed in those frameworks, but might need manual curation to be feedable to the generated ontology.

The UVON method creates an ontology from the flat list of qualities elicited from users or extracted from an evaluation framework.¹⁶ Although UVON is algorithmic and semi-automated, two types of decisions require human decisions. The first is to determine if a quality aspect is a more specific version of another quality aspect. The second decision, somehow the reverse of the first, is to find a quality that is a more generic form of a set of qualities. These two decisions can also get automated by text analytics methods. Through lexical databases, such as WordNet,²¹ a piece of software can find relationships between two terms concerning how close they are or if in the hierarchy one is an abstract form of the other (hyponym and hypernym relationship).^{21,22} This approach alongside automated elicitation methods can replace the need for recruiting human agents to run the UVON method or at least minimise the need for human intervention.

If one does not need to replace a user response with automatically collected measures, this step would be the end of the automated evaluation system, sufficing the automation of eliciting evaluation aspects and creating questionnaires based on that.

12.4.2 Collecting Baseline Data

THE next step is to gather users' attitudes about the system's performance regarding users' previously requested qualities or the evaluation aspects suggested in the evaluation framework. Figure 12.3 depicts this part, called the *User Survey* component. This initial evaluation result is needed to create a baseline for further automation. The finding can be used

17: Ryan 1993

18: Lloret et al. 2012

19: Saggion et al. 2013

20: Breux et al. 2014

21: Varelakis et al. 2005

22: Kamps et al. 2004

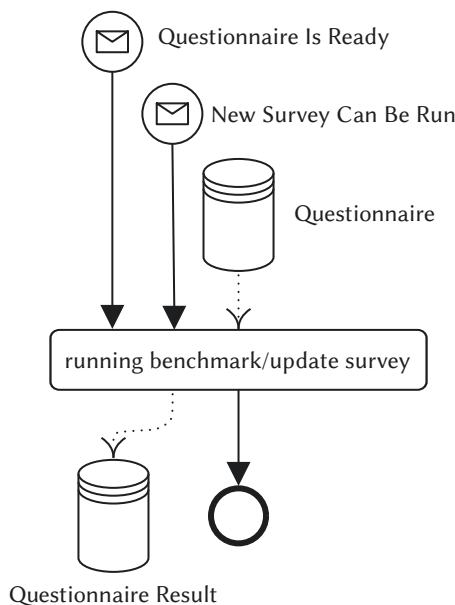


Figure 12.3: User Survey component: Collects data by running a survey, using the questionnaire.

to find the automated metrics that match. As shown in the figure, it is possible to rerun and update the survey result when it is required and possible.

12.4.3 *Creating the Benchmark Path Model*

THE next component of the automated evaluation system, Figure 12.4, creates a benchmark path model. The path model represents the relationships between the previously elicited qualities and user satisfaction or acceptance variables. The strength of relationships in the path model can be quantified using different methods, but for our purpose, a kind of structural equation modelling (SEM) approach, such as partial least squares structural equation modelling (PLS-SEM), is required. The PLS-SEM path modelling technique has been used for modelling causal relationships related to user satisfaction or acceptance, such as the Customer Satisfaction Index (CSI),^{23–25} Delone and McLean Information Systems Success (D&M IS),^{26,27} Technology Acceptance Model (TAM),²⁸ and other similar intentions.²⁹ The authors have used PLS-SEM for modelling the relationships between qualities elicited by the UVON method.³⁰

Figure 12.4: Benchmark Path Model component, Benchmark Path Model

23: Fornell 1992
24: Fornell et al. 1996
25: Henseler et al. 2016
26: Hsu 2008
27: Livari 2005
28: Gefen et al. 1997
29: Hair et al. 2014
30: Eivazzadeh et al. 2018

The PLS-SEM path structure consists of a series of constructs, or

latent variables, unidirectionally connected. It is assumed that the constructs cannot be measured directly—that is why they are called latent—but each one reflects or manifests itself through a set of other measurable variables which are called measure or manifest variables.

THE *Evaluation Aspects Elicitation* component (see Figure 12.2), applies the UVON method to suggest the constructs and their associated manifest variables to be included in the path model. This suggestion is in the form of two layers of qualities, whereby each quality in the first layer is associated with one or more specific qualities in the second layer. The suggestion input is labelled *Qualities in Two Levels: UVON Suggested Constructs & Manifests* in Figure 12.4.

Conversely, a correlation matrix can help to explore relationships further³¹ or confirm the UVON suggested ones. The correlation matrix is calculated for qualities found in the questionnaire created by the *Evaluation Aspects Elicitation* component and surveyed by the *User Survey* component. Note that these qualities are the same as the qualities in the second layer of the *Qualities in Two Levels: UVON Suggested Constructs & Manifests*. It is expected that qualities that associate with the same quality in the first layer show a higher correlation between each other. Optionally, the correlation matrix can be rearranged, for example by the angular order of the eigenvectors (AOE) method, for the better visualisation of possible groupings.³²

The final output of this step is the *Suggested Constructs & Manifests* that must be combined with a path structure type.

A pool of path model archetypes helps to consider the path structure. The relevant and well-studied models for success, user acceptance, or user satisfaction, such as TAM,^{33,34} Extended Technology Acceptance Model (TAM2),³⁵ Unified Theory of Acceptance and Use of Technology (UTAUT),³⁶ CSI,²³ American Customer Satisfaction Index (ACSI),²⁴ European Customer Satisfaction Index (ECSI),³⁷ and D&M IS^{38–40} can be considered archetypes from which the path structure is adopted partially or to the full extent. Choosing a path structure type depends on what qualities are measured, what constructs have been suggested by the UVON method, and how the constructs can be matched to an archetype.

Now, the previous output, the *Suggested Constructs & Manifests*, can be mapped to a chosen path structure archetype and create the path model.

:process, consider UVON suggested constructs & manifests

31: Friendly 2002

32: Friendly et al. 2003

:process, create the path model structure

33: Davis 1989

34: Holden et al. 2010

35: Venkatesh et al. 2000

36: Venkatesh et al. 2003

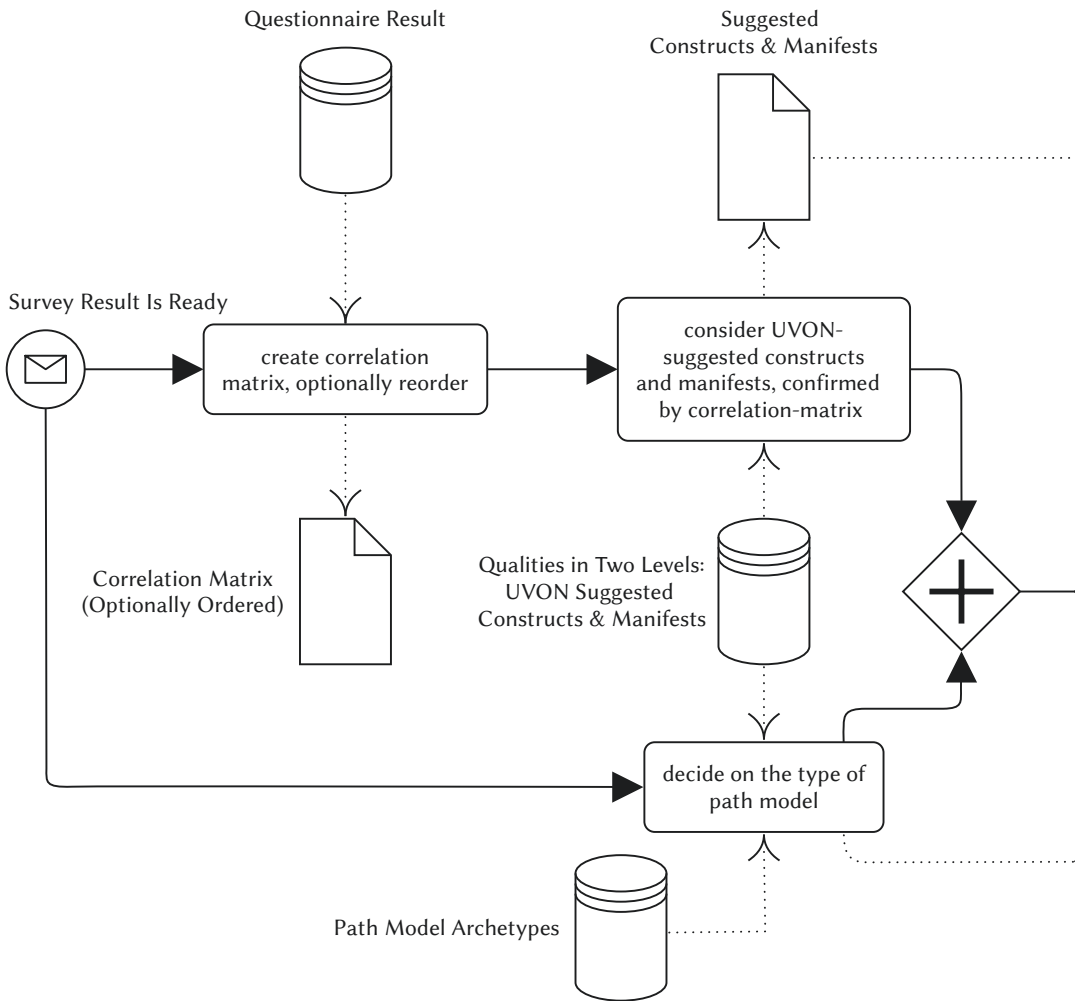
37: Bayol et al. 2000

38: DeLone et al. 2003

39: Urbach et al. 2012

40: Petter et al. 2008

:process, estimate the model relations



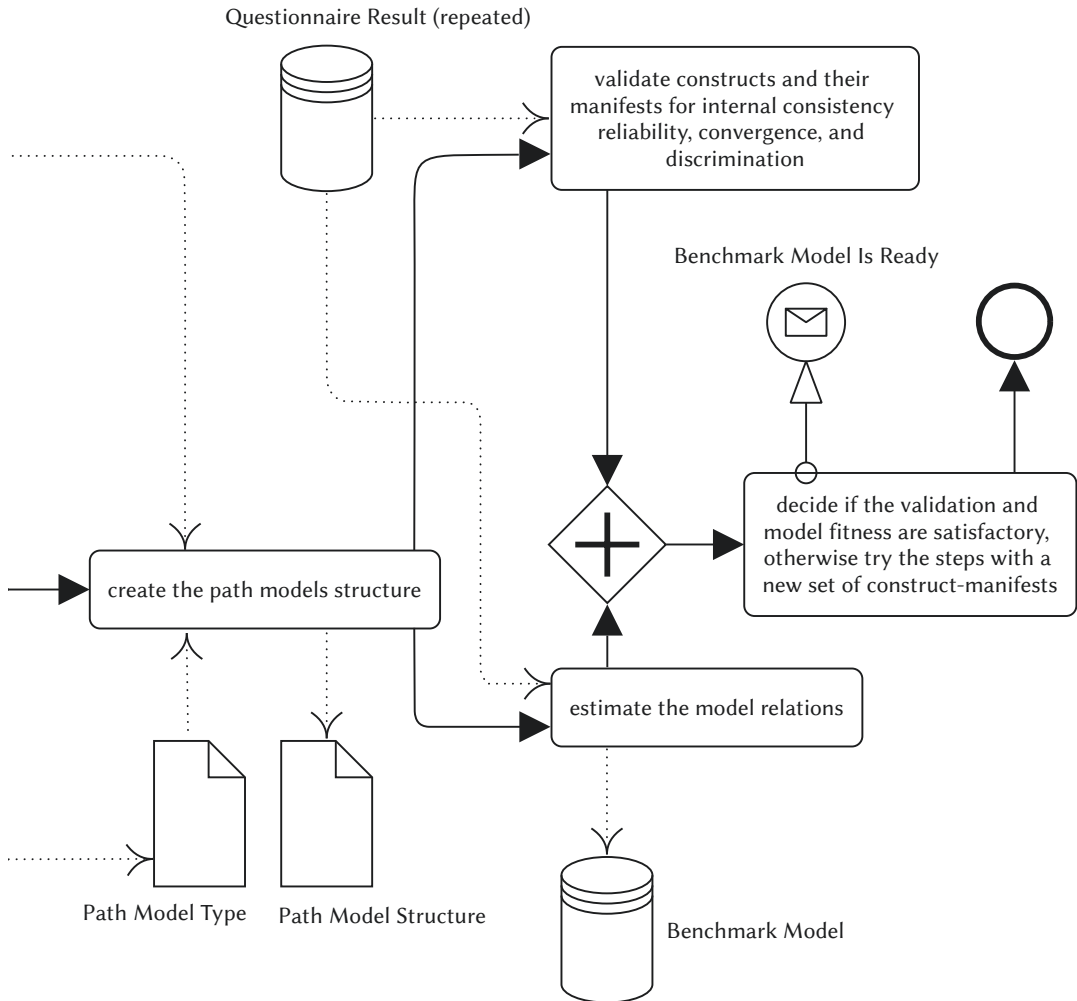


Figure 12.4: Benchmark Path Model component: Determines the path structure, its constructs, and their associated manifests. Subsequently, it estimates the model coefficient and loading values.

AFTER determining the structure, the path model relationships should be estimated, for example by using PLS-SEM, investigated, and validated. In this step, various conditions are checked: if the model can describe or predict an acceptable amount of variations in the satisfaction variable by quality variables, that means the model's coefficient of determination R^2 is in an acceptable range for social science; if the significance of relationships, such as the p-values, is enough; if the constructs vary sufficiently from each other, considering the manifests assigned to them—this discriminant analysis can be done by a method such as heterotrait-monotrait (HTMT);⁴¹ if the manifests of each construct are measuring the same thing, by running internal consistency composite reliability (CR) and convergence validity average variance extracted (AVE) methods;^{42,43} finally, if there is good overall fitness, by calculating indices such as Goodness of Fit⁴⁴ and the standardised root mean square residual (SRMR).⁴⁵ This process can improve results if the validation indicators are not satisfactory by examining limited tweakings in the construct-manifest sets or the path structure.

41: Henseler et al. 2015

42: Henseler et al. 2012

43: Chin 1998

44: Henseler et al. 2013

45: Hu et al. 1998

12.4.4 Determining Metric Alternatives of Manifests

THE next component of the system, *Alternative Metrics Replacement* (see Figure 12.5), enables the continuous evaluation and dynamic analysis feature by substituting user-requested quality indicators in the benchmark model with their equivalent automatically measurable metrics. Automated metrics, in this sense, are types of indicators that are supposed to reflect the implicit attitude of users, unlike the explicit expression of attitudes in an instrument such as a questionnaire. Considering each quality is represented by a manifest variable in the benchmark model, the substitution process must find a highly correlated replacement metric or set of metrics for each manifest. Nevertheless, the replacement process should maintain a similar or acceptable range of validation and fitness values. Notably, collecting candidate correlative automated metrics is only facilitated by the system and cannot be fully-automated. There should be a human judgment about the real relationship between the correlative automated metrics and the original user opinions about a quality; otherwise, spurious correlations might be introduced into the model.

what does it do?

After performing the substitutions in the model, the coefficients and loading of the path model are calculated again, and the model becomes

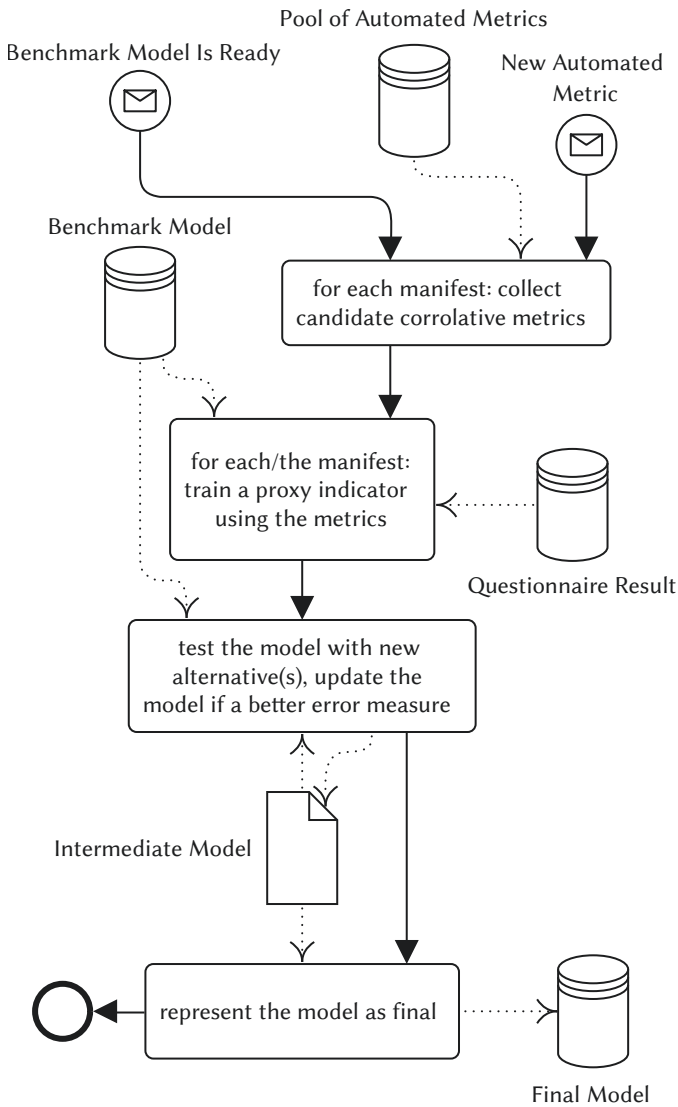


Figure 12.5: Alternative Metrics Replacement component: Attempts to replace user-requested quality indicators with the equivalent automated metrics.

ready to be utilised for the continuous evaluation or prediction of the outcome variables, such as user acceptance or satisfaction. The system can also evolve and adapt to a new situation by introducing new automated metrics, retiring less-efficient automated metrics, or changing the whole structure of the path model. This evolving and dynamic adaption enables the evaluator to dynamically analyse and evaluate the system, despite changes in data sources. This possibility is what we call the *dynamic analytics feature of the evaluation system*.⁴⁶

46: Hupert 2013

THERE is a rationale behind the approach of replacing user-requested manifest variables with automated metrics. Using automated metrics directly instead of manifest variables can be challenging, more prone to mistakes, and less verifiable for authenticity. The manifests in our system originated from stakeholders and users themselves or a tested evaluation framework; therefore, their semantic relationships are sound. Moreover, in the *Benchmark Path Model* component, those relationships have been explored by inspecting the correlation matrix and validated by calculating various relevant indices. However, automated metrics are rooted in what we can measure by assessing sources such as the logs of the health information system, the logs of other connected systems, and sensors and other environmental data. The relationship of automated metrics to the constructs and their manifestation should be established and proven. Therefore, instead of directly introducing arbitrary automated metrics into the path model, we try substituting user-requested quality manifests with a set of automated metrics that show similarity and correlation in their behaviour.

:why one cannot directly use the implicit automated metrics

THE *Benchmark Model is Ready* event starts this component, and the *New Automated Metrics* event restarts it for another round of functioning. A first requirement for the component's functioning is the availability of the *Pool of Automated Metrics* (see Figure 12.5). The *Pool of Automated Metrics* is a collection of measured automated metrics. In other words, it is a log file containing different measurable automated metrics collected from users and stored as a time series of data points. An example of such automated metrics can be the daily duration of each user's utilising the subject system. The pool contains both basic and compound automated metrics, where the compound automated metrics are not directly collected but calculated from basic ones. Each metric is associated with a catalogue that enlists the basic metrics used in

:process, collect the candidate correlative automated metrics

the compound one. This catalogue helps to avoid collinearity or multicollinearity problems when a set of metrics might need to be combined.

IN the next step, for each manifest variable, the evaluator interacts with the system to select a set of metrics from the pool that together can represent a proxy indicator as an alternative to the manifest. If the evaluator finds an automated metric or a combination that seems to match a manifest, probably with a high correlation ratio, the metric can be considered a predictor of the manifest. For example, one might find the number of logins by users is a good metric to represent the acceptance of the system and there is a considerably high correlation between the metric and questionnaire-based responses to system acceptance. To extend the example, one might discover the number of logins is not a good indicator for acceptance, because users log into the system for the minimal usage of a specific minor feature, or they just try to find their way around in desperation. A better metric, that is more correlated with the user-declared acceptance, might be the number of logins that the user has spent more than a specific amount of time in the system. In any case, the metric not only should be semantically related to the user-requested quality indicator, but also it should show a high degree of correlation with the manifest variable and does not considerably deteriorate the whole model validation or fitness indices. When it is not possible to find a replacement in the automated metrics for a user-requested manifest indicator, the indicator can be replaced with the average value of the variable. This is a partial compromise on the continuous evaluation and dynamic analysis features for the sake of the validity of the whole evaluation system. *:calculating the proxy indicator*

The relationship between a user-requested quality indicator, that is a manifest variable, and its corresponding automated metrics can be considered a classification problem. The proxy indicator is estimated from a metric or set of metrics, and it replaces and represents a manifest, though with a residual. The survey result data type is usually ordinal, like a Likert scale, while automated metrics can be any type. The general formulation of the classification can be that a set of covariates of any type predict an ordinal variable. We intentionally avoid calling the covariate an independent or explanatory variable, because in our case, the causal relationship is usually reversed. Methods of statistical learning or machine learning can be used to estimate a user-requested quality indicator. The estimated variable is the proxy indicator that replaces the estimated user-requested quality manifest if it can maintain the validity and fitness

constraints of the whole model.

There is a combinatory set of different replacements, and each replacement of a manifest variable with its proxy variable counterpart results in a new candidate intermediate model. All the candidate models should be verified, and their fitness indices calculated. The final model is decided by the fitness of the model and the number of manifest replacements by proxies.

THE design above makes continuous evaluation and dynamic analytics possible. The continuous evaluation becomes possible by minimising the need to request users to provide their attitudes about different aspects of the health information system, instead of relying on automatically and continuously measured metrics. In addition, being able to re-estimate the relationships in the path model enables an evaluator to recruit new automated metrics, retire less efficient ones, or change the whole structure of the path model dynamically.

:continuous semi-automated
evaluation and dynamic
analysis

12.5 Demonstration and Results

PARTS of the solution provided in the Section 12.4 already have been implemented in the evaluation of the Future Internet Social and Technological Alignment Research (FI-STAR) project and the authors' studies based on that. The FI-STAR project was funded by the European Union (EU); seven e-health applications were developed using the Future Internet WARE (FIWARE) platform across seven EU member states.^{47,48}

47: FI-STAR Consortium
2014

Like the *Evaluation Aspect Elicitation* component (see Figure 12.2), the UVON method was applied in the FI-STAR project.¹⁶ At first, the requirement engineering activities at the beginning of the FI-STAR project specified a set of qualities. Users of the e-health applications requested these qualities and expected them to be improved as the outcome of using those applications. Then, the UVON method created two questionnaires, for patients and health professionals, based on those qualities and the evaluation aspects specified in the Model for ASsessment of Telemedicine applications (MAST) framework.⁴⁹ After the implementation and deployment of the e-health applications, patient and health professional users were asked to fill in the questionnaire. In the design proposed in this study, the *User Survey* component was assigned for running the survey (see Figure 12.3), regarding the requirement of being able to rerun surveys when updated data on user attitudes is needed.

48: Publications Office of the
European Union 2016

49: Kidholm et al. 2012

The result of the survey was then used in another study to find the most influential qualities in creating satisfaction.³⁰ The study used both the correlation matrix and path modelling approach utilising PLS-SEM, similar to *Benchmark Path Model* component in Figure 12.4. Similarly, in that study, the relationship between influential qualities and satisfaction is quantified by the PLS-SEM method.

12.6 *Evaluation and Discussion*

FROM the evaluation of the design perspective, some components' parts and their embedded mechanisms of the proposed design are already validated. For components 1 and 2 (Figures 12.2 and 12.3), the elicited evaluation aspects and the result questionnaire, resulted from applying the UVON method in the FI-STAR project, were validated by case owners and users (patients and health professionals).¹⁶ Furthermore, the discriminatory and reliability validations from PLS-SEM models in another study³⁰ confirmed that again. The same study also validated the method of creating a benchmark path model, which was used in component 3 (Figure 12.4). Component 4 (Figure 12.5) comes with novel approaches that need to be assessed in a real-world testbed.

THE design presented in this study automates major tasks in a typical evaluation endeavour. These automations also enable some of those tasks to run continuously. There are also features, such as handling the heterogeneity of subject systems or the dynamic evolvement of the evaluation model, which are not usually or easily available in typical evaluations. A summary of the provided features, their enhancement as automated or continuous, and the major implementing components of each feature is represented in Table 12.1.

12.7 *Conclusion*

WE provided the design of a system that minimises the burden of human agents, evaluators, and respondents in a survey-based evaluation. This reduction in the burden mostly happens through the semi-automation of specific tasks: finding out what to evaluate, creating a questionnaire based on those findings, implementing the survey, modelling the relationship between evaluation aspects, and evolving the model to decrease

Table 12.1: Summary of automation and continuity features embedded in the design.

Requirement	Automation			Continuity			Components ^b			
	Full	Semi	None	Full	Semi	None	1	2	3	4
First level ^a										
To know: If the users are satisfied with the system	●			●				+ ²		+ ⁴
The system continuously checks user satisfaction. In the component 2, it is asked directly, and in component 4, it is monitored by assessing automated metrics that predict satisfaction. A limitation is when users change their preference and qualities no longer predict their satisfaction.										
To know: Which impact qualities are considered important, by users or domain experts		●			●			+ ¹		+ ⁴
Using the UVON method, one still needs to decide the categorization of each quality. The design does not propose new important impact qualities but can detect if satisfaction is not in sync with quality indicators or new demanded qualities appear in text analysis.										
To know: Which impact qualities are common amongst a set of heterogeneous systems (least common denominators)		●			●			+ ¹		+ ⁴
The UVON method finds the least common denominator (also called commonalities) of impact qualities. However, one must decide the categorisation of each quality. A text analytics approach might fully automate the process.										

continued on the next page.

Table 12.1 – continued from the previous page

Requirement	Automation			Continuity			Components ^b			
	Full	Semi	None	Full	Semi	None	1	2	3	4
To know: Which qualities of the impact create the most user satisfaction (comparable)		●				○				+ ³
	This relies on using the UVON method and deciding the general structure of the model. Hence, it is semi-automated. However, once the most influential qualities are discovered, they are not being rediscovered continuously. The designed system can detect if satisfaction is not in sync with quality indicators or new demanded qualities appear in text analysis.									
To know: How the users evaluate each impact quality that creates user satisfaction	●			●				+ ²		+ ⁴
	Component 2 collects users' attitude about each quality. Component 4 replaces it with metrics that are collected continuously and automatically.									
Integrating a new case into previous evaluation cases (being dynamic)		●			●		+ ¹			
	New cases might be introduced to the system, and the system adapts its output regarding its new findings. However, the UVON method and survey need to be rerun, which necessitates evaluators and users' involvement.									
Second level ^a										
Creating the questionnaire		●					+ ¹			
Running the survey	●							+ ²		

continued on the next page.

Table 12.1 – *continued from the previous page*

Requirement	Automation			Continuity			Components ^b			
	Full	Semi	None	Full	Semi	None	1	2	3	4
To know: Which qualities can be considered construct variables, and which can be manifests to those constructs in a path model?	●			●			+ ¹		+ ³	
				In component 1, the UVON method structures the qualities as a hierarchy in the output ontology. The selected layer for creating a questionnaire provides constructs, and the child nodes, if they exist, provide manifest variables.						
Creating a path model involving user satisfaction and impact qualities		●							+ ³	
Replacing the need for users' explicit expression of attitudes with implicit indicators (automated metrics)		●								+ ⁴

^a First-level requirements are supposed to directly refer to the needs of a typical evaluation. The first-level requirements are contingent on second-level requirements, due to the design. Hence, with a different design, another set of requirements might appear in the second level. The feature of continuity might be non-applicable for some of the second-level requirements.

^b While the components of a higher number depend on the previous ones, here, we only mention the components which contribute more directly in satisfying the requirement.

its dependence on the indicators that need the intentional interaction of a human agent.

Beyond minimising the need for a human burden, the design provides another set of features. The component that determines what to evaluate can perform its function even for a heterogeneous set of systems. The proposed system can run evaluation continuously or very frequently. In other words, the designed evaluation system enables the real-time monitoring of users' attitudes about the impact of the subject system. As a secondary effect of relying on implicit indicators, the evaluation system can be improved and adapted to the changes in the environment by choosing a different set of those indicators, without interrupting the workflow and involving the users in this change. The proposed design tries to find the optimal point between objectivity and subjectivity in evaluation. It begins with subjective—but more holistic—indicators, that is the set of user attitudes; and it tries to replace objective indicators as much as it does not disturb the whole balance between the indicators.

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PART III

APPENDICES

A

Questionnaire for the Patients in FI-STAR

1. [pa.general.sat.1](#): How satisfied are you with the application's health care output in its entirety?
2. [pa.general.sat.2](#): How well the application fulfills your expectations in health care delivery?
3. [pa.general.sat.3](#): Imagine a perfect application in all aspects of health care delivery. How far away from that is the application you are using today?
4. [pa.adherability](#): Adherenceability:: The application increased my motivation for the treatments
5. [pa.affordability](#): Affordability:: The health care service delivered through the application is more affordable or decrease expenditures, comparing with other alternatives.
6. Efficiency If you have experienced the same treatment before, would you say that the application has increased efficiency by reducing:
 - a. [pa.efficiency.1](#): Complexity or number of tasks
 - b. [pa.efficiency.2](#): Number of reworks
 - c. [pa.efficiency.3](#): Time consumed
7. Effectiveness The application has increased effectiveness, especially by improving at least one of these items:
 - a. [pa.effectiveness.1](#): Less mistakes
 - b. [pa.effectiveness.2](#): Readiness or promptness for different situations
 - c. [pa.effectiveness.3](#): More personalized treatment

8. [pa.empowerment.3](#): Empowerment The application empowers me by increasing my knowledge about the situation or general knowledge about the disease.
9. Safety
 - a. [pa.safety.1](#): I felt safe when using the application.
 - b. [pa.safety.2](#): The application provides correct information without any mislead or confusion.
 - c. [pa.safety.3](#): I felt that the application helped me to minimize possible harms during the usage.
10. [pa.trustability](#): Trustability I felt that I can trust the application for my privacy and my information.

B

Questionnaire for the Health Professionals in FI-STAR

1. [pr.general.sat.1](#): How satisfied are you with the application's health care output in its entirety?
2. [pr.general.sat.2](#): How well the application fulfills your expectations in health care delivery?
3. [pr.general.sat.3](#): Imagine a perfect application in all aspects of health care delivery. How far away from that is the application you are using today?
4. [pr.accessibility](#): Accessibility The application is easily accessible for different groups of users
5. [pr.adhereability](#): Adhereability The application helps patients to more adherence by some sort of motivators (i.e. being a member of a community)
6. [pr.affordability](#): Affordability The health care service delivered through the application is more affordable or decrease expenditures, comparing with other alternatives.
7. [pr.availability](#): Availability The service which is provided by the application, is available on demand
8. Efficiency The application has increased efficiency by reducing
 - a. [pr.efficiency.1](#): Complexity or number of tasks
 - b. [pr.efficiency.2](#): Number of reworks

- c. [pr.efficiency.3](#): Time consumed
9. Effectiveness: The application has increased effectiveness, especially by improving at least one of these items:
- a. [pr.effectiveness.1](#): Less mistakes
 - b. [pr.effectiveness.2](#): Readiness or promptness for different situations
 - c. [pr.effectiveness.3](#): More knowledge and evidences
 - d. [pr.effectiveness.4](#): More personalized treatment
10. Empowerment
- a. [pr.empowerment.1](#): The application empowers the patient by increasing their knowledge about their situation or general knowledge about the disease.
 - b. [pr.empowerment.2](#): The application empowers the medical personnel by increasing their knowledge about the patient situation or general knowledge about the disease.
11. Safety
- a. [pr.safety.1](#): It is safe for the patients to use the application without any possibility of disability, morbidity, or mortality harm.
 - b. [pr.safety.2](#): It is safe for the medical personnel to use the application without any possibility of disability, morbidity, or mortality harm.
 - c. [pr.safety.3](#): The application provides correct information without any mislead or confusion.
 - d. [pr.safety.4](#): The application provides enough information on how to minimize possible harms during the usage
 - e. [pr.safety.5](#): If the application fails, and if the failure causes any harm, then the harm would be minor as it would be non-severe, rarely happening, or happening for a very short duration.
 - f. [pr.safety.6](#): The application improves health care safety by detecting emergency situations, unsafe behaviors or glitches in the process.
12. [pr.trustability.1](#): Trustability The application attains trust of patients (for example by ensuring privacy of their information or being non-invasive in its interaction with them)

End Notes

I. For preparation of this dissertation various open source softwares were used. The text of this book is authored in `ASCIIDOC`, a human-readable document format. Then it is converted from `ASCIIDOC`, through a tool-chain called `ASCIIMINT`, into typesetting and presentation formats in `Latex (luatex)`. Shahryar Eivazzadeh developed `ASCIIMINT`, by using or combining several open-source software applications, including but not limited to `ASCIIDOCTOR`, `Nodejs`, `Dblatex`, and several `Latex` packages (>160), including but not limited to `tufte-book` and `biblatex`. Data analysis and visualizations were performed mostly in `R` and its libraries, including but not limited to the `tidyverse` collection. Other illustrations have been made using `Inkscape` or `tikz`. Open source fonts were used, `EB Garamond` for text and `LINUM BIOLINUM` for illustrations. Styles of visualizations and typography are inspired by E.R. Tufte's works. Many of technical questions were already answered, or found new answers, by the users of the `Stackexchange.COM` community.

II. The opening of *The Elephant in the Dark Room* story in *Masnavi* by Rumi (1207–1273).

III. Discourse of Shams Tabrizi by Shams Tabrizi (1185–1248).

IV. In Swedish, *kappa* means the garment that covers head,¹ where in the academic environments of some Nordic countries, it means the introductory part to a dissertation, wrapping the papers in next parts. It is originally from late Latin *cappa* "a cape, hooded cloak".² It is a cognate with Middle Persian (Pahlavi) *kabāh* "garment, cloak"³ and Modern Persian *qabāh* (as in the cited poem from Rumi), ultimately from Proto-Indo-European *(s)kep-* "to split, cut".²

V. The icons used in the figure are designed by the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) and belong to public domain.⁴

1: Svenska Akademien 2015

2: Douglas Harper 2015

3: MacKenzie 2014

4: United Nations Office
for the Coordination of
Humanitarian Affairs 2018

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ABSTRACT

Health information systems are our technological response to the growing demand for health care. However, their success in their mission can be challenging due to the complexity of evaluating technological interventions in health care. In the series of studies compiled in this dissertation, we looked at the evaluation of these systems. The dissertation is focused on the evaluation of factors that lead to success, where success is indicated by user satisfaction and can be induced by both intervention-specific and individual-specific factors.

Study 1 developed a method, called UVON, to elicit and organise the user-demanded qualities in the outcomes of the health information system intervention. Through the application of the UVON method in the FI-STAR project, an EU project which developed and deployed seven e-health applications in seven member countries, ten categories of quality and their subcategories were identified. These qualities formed two questionnaires, specific to the patient and health professional users. Through the questionnaires, the patients and health-professionals users evaluated and graded both the occurrence of those demanded qualities in the project outcomes and their general satisfaction.

Study 2 analysed the survey results to find out which of those ten qualities have the highest impact on satisfaction or can predict it better. Two partial least squares structural equation modelling (PLS-SEM) models were constructed, for the patient and health professionals, based on the Unified eValuation using ONtology (UVON) and survey outputs. The models showed that effectiveness is an important quality in creating satisfaction for both user groups. Besides, affordability for the health professionals and efficiency plus safety for

the patients were the most influential. A satisfaction index is also introduced for simple and fast inferring of the changes in the outcome qualities.

Study 5 recruited outputs and learnings from studies 1 and 2 to design a system that partially automates the process of evaluating success factors in health information systems, making it continuous and real-time, and replacing hard-to-run surveys with automatically captured indicators and analytics.

Study 3 focused on individual-specific factors in using health information systems, particularly the technophilia personality trait. A short six-items instrument, called TechPH, was designed to measure technophilia in users, tuned for older users. The study recruited empirical data from the Swedish National Study on Aging and Care (SNAC) project. Two factors, labelled techAnxiety and techEnthusiams, are identified by the factor analysis method. A TechPH score was introduced as a scalar measurement of technophilia.

Study 4 elicited and discussed the ethical challenges of evaluating and researching health information systems. Both a scoping review and a novel systematic postulation approach were recruited to identify twenty ethical challenges. The identified ethical challenges were discussed and mapped into a three-dimensional space of evaluation stages, demanded qualities, and major involving entities (stakeholder and artefacts), which fosters further postulation of ethical challenges.



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