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Building the Bridge between Operations and Outcomes

Modelling and Evaluation of Health Service Provider Networks

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Mahdi Mahdavi

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Building the Bridge between Operations and Outcomes

Modelling and Evaluation of Health Service Provider Networks

Bouwen aan de brug tussen operations en uitkomsten.
Modellering en evaluatie van netwerken van zorgaanbieders

Thesis
to obtain the degree of Doctor from the
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Mahdi Mahdavi

Born in Hamedan, Iran

ERASMUS UNIVERSITEIT ROTTERDAM

Doctoral committee
Promotors:

Prof.dr. J. Vissers

Prof.dr. J. van de Klundert

Other members:

Prof. dr. R. Huijsman, MBA

Prof. dr. P. Lillrank

Prof. dr. W. Sermeus

Content

Chapter 1

General Introduction

Introduction

Current health service organizations face an increasingly complex demand. Populations are aging and life style diseases such as diabetes and cerebrovascular diseases are rapidly expanding, resulting in a growing prevalence of chronic conditions that threaten the quality of life of populations [1]. It is therefore important to understand how the health services for these conditions influence patient outcomes in terms of health state, quality of life, and satisfaction with services.

The service provisioning for age and life style related conditions, which are often complex and chronic, often involve multiple health service provider organisations, as each of them only provides a subset of the provided services. [2]. The changes in demand for health services thus increasingly cause provider organisations to jointly establish networks which service the demands of a population of health service users in their region [3]. Such provider networks have become increasingly common in the management of healthcare for chronic conditions such as diabetes and COPD [4], as well as in the treatment and care of many other complex conditions such as stroke [5]. These networks may be formed as (formal) collaborative networks for particular interventions or as a structural component of healthcare delivery systems. In the absence of formal relationships, such networks may still be practically defined as a collection of health service providers jointly visited by (a population of) health service users [6].

As the outcomes obtained for the health service users serviced by a network depend on the joint performance of health service providers involved, the understanding of service performance also requires a network perspective. At present however, the evidence base for service operations in health service provider networks is scarce and in an early stage of development [7]. The little evidence on health service operations management available mostly applies to the relationships between operations and outcomes at departmental or organizational level. Thus, the recent call to advance the evidence base of health services management by Rousseau et al., who advocate the use of rigorous evaluation to synthesize an evidence base for effective health services provisioning [8], particularly applies to health service networks.

The establishment of an evidence base for service operations in health service provider networks requires a well-conducted research investigating the relationships between the service operations and the outcomes. Such relationships have received attention since the seminal work of Donabedian [9], presenting the structure-process-outcome (SPO) model, which forms the basis for many models in health services research. These models however are weakly connected to the service operations management literature, and the models and methods available therein. Conversely, a large number of alternative models has been proposed in the service operations management literature [10]. Health service operations management regards the planning, design, and delivery of health services that are used to meet user demands and expectations and to improve outcomes [11]. Among the models available from health service operations management literature, operational models are defined as formal descriptions of health service operations, which capture the details required to facilitate operational (as opposed to strategic or tactical) decision making [12]. Despite the vast body of literature on operational models, general public, professionals, and researchers alike, call for enhanced understanding of the effectiveness and/or efficiency of health service operations [13]. It appears that the models and methods from health service operations management have difficulty reaching practitioners, thus limiting the use of the models and the evidence base [14]. Moreover, few models from health service operations management model patient outcomes, the pillar of any evidence-based approach. Instead, the majority of these operational models are case studies describing tightly bounded elements of health service networks rather than the network, and report on operational performance measures. In contrast to earlier calls for wide ranging generic models [15], contributions to progress beyond current specific narrow-ranging models have been rare.

Hence this thesis aims to advance the understanding of the effects on outcomes of health service operations in provider networks, and specifically the evidence base. We do so by taking an approach which combines health services research and services operations management. The focus will be on contributing to the evidence base of health service operations in provider networks, in response to the aforementioned calls. The PhD research has two objectives:

- To develop generally applicable operational models which allow developing the evidence base for health service operations in provider networks.
- To contribute to the evidence base by validating the model through application to health service networks for type 2 diabetes, stroke, and hip osteoarthritis.

Conceptual framework: evidence based operations management in health service provider networks

Evidence-based health service management is about informed managerial decision making by the best available evidence from well-conducted research [16]. There is a gap in the use of research evidence for managerial decision making. The overuse of ineffective interventions, misuse of interventions with unclear effectiveness, and underuse of effective interventions, as are common in evidence based medicine, are also reported in health service management [17]. Although context and content of health service management hinder the use of EBM, its basic principles can also be applied to health service operations [18].

An evidence based approach in health service operations requires to develop operational models which can be reused in different networks, thus allowing replication of studies and therefore to enhance external validity and generalizability [10]. Hence they must share outcome indicators, as well as the models and measures to define the health service operations in the networks. The approach we take in this thesis is based on the aforementioned SPO model of care in which structure influences processes and both determine health outcomes. In this thesis, we view the processes as services. The generic conceptual model of health service operations of provider networks used in this thesis (See Figure 1-1) borrows its *Service, Structure, and Outcome* core from the SPO model.

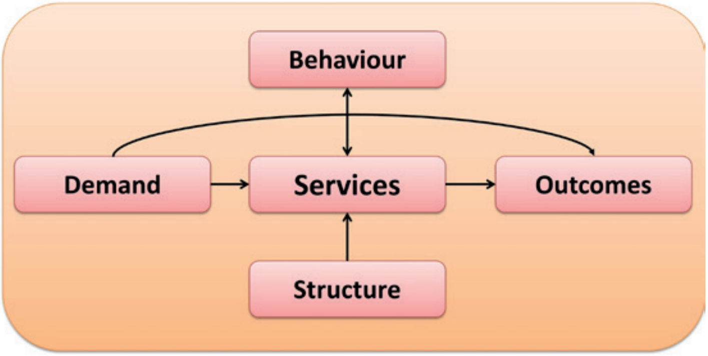

Figure 1-1 Generic model of demand, services, structure, behaviour and outcomes

Multiple (different) contexts are in place in provider networks, that confound with effects that interventions in the structures or services of operations would have on outcomes across organizations [19]. This weakens the external validity of evaluation studies which solely address the intervention in a single organization (while disregarding context), however rigorous the study design and protocol may be. Berwick [20] points out studies often have failed to regard local context details in the service provisioning which essentially influences outcomes. In order to advance externally valid evidence he advocates the use of techniques from the discipline of operations management.

The CIMO logic, as for instance discussed in Van Aken [21], aids to take context into account when researching health service operations. The CIMO logic considers Context next to Intervention to explain Outcomes, and seeks for (generic) Mechanisms which explain how Outcomes are influenced by both [21]. The Context construct in the CIMO logic is more general than the Structure construct of the SPO-model. In the conceptual model considered in this thesis, we therefore extend the SPO model by taking additional contextual factors into account. In part, this will be achieved through using generic and specific models as explained below. As a generic extension of the model however, we extend the model by including geographical and demographical characteristics to characterize the demand context (in addition to the supply oriented structures and services). Moreover, borrowing from state of the art service science literature [22, 23], our conceptual model explicitly considers the co-creation of health service users, as a determinant of outcomes – in interaction with the service provisioning by provider organisations which is captured by the model entity Behaviour. This co-creation enables to model contextual phenomena which are increasingly seen as important for future health services such as health behaviour, self-management, shared decision making, compliance, et cetera.

In addition to these generic model extensions, we propose to consider 'local contextual details' of structures, demand, and behaviour, as they may play an essential role in the outcomes achieved. Oftentimes such details are disease or region specific. The proposed models therefore need to be able to capture local region specific and disease specific details of services, structures, behaviour, and demand – thus enabling to include local context as relevant, and at the same time enabling external validity of analysis findings, and discovering general mechanisms, where possible. Hence, in addition to further elaborating the generic model presented in Figure 1-1, we provide methods for adaptation and refinement of the models when appropriate to different diseases and regions.

Adjusting the generic models to a specific disease, to derive what will be referred to as disease specific models, a process referred to as specification, serves as an intermediary step as the ultimate purpose is to describe local details of regional provider networks. The actual description of a regional network for a specific disease model (to be called an instance), is subsequently referred to as instantiation. Thus, the model allows developing an evidence base for health service provider networks for specific diseases by considering different instances, i.e. different regional networks, for a same disease specific model. Moreover, it allows generating evidence across diseases, by comparing evidence for various disease specific models through their common generic model basis.

Study aims and research questions

As a first step of this research we synthesize research evidences on health service operational models by a systematic review. There is to our knowledge no such study that synthesizes state of the art scientific literature in health services operations management [18]. Our research can be viewed to parallel the development of evidence based research in health services research [24, 25]. This research synthesis specifically addresses research evidences on dimensions of health service operational models.

1) Which models exist for health service operations, what are the purposes of these models, the application areas, the modelling methods, and achievements?
2) What understanding and evidence have existing models for health service operations delivered regarding patient outcomes?

An answer to the above questions provides a summary of evidence on the dimensions of health operational models and contributes to compile a methodology to advance the development of an evidence base for health service operations in provider networks.

Based on lessons learned from the review study we propose a generic framework to derive models for health service network operations. The resulting models capture the characteristics of processes and outcomes as called for by the Medical Research Council [26], as well as contextual characteristics of the provider networks as recalled by Berwick [20]. Yet, contents of components need to be clearly defined in order to enhance the internal validity of the generic model. Furthermore, mechanisms to specify disease models and to instantiate a disease model to instances must be clearly defined for further reuse of the models and validity testing. We therefore set out to answer the following questions:

3) Which components are generically appropriate to be included in the models to advance the evidence base, in particular with regard to the validity of relationships between operations and outcomes in regional provider networks?
4) How to subsequently facilitate adjustment of the generic model as needed to derive disease specific models (specification) and characterize corresponding

regional health service networks (instantiation) with disease specific and regional contextual detail?

We test if the aforementioned modelling framework provides a generalized applicability to facilitate reuse of modelling components for various cases and therefore to advance the understanding and evidence base for health service operations. To this purpose, we derive disease specific models from the general model for Type 2 Diabetes (T2D), stroke, and hip osteoarthritis (hip OA). These conditions differ in nature and present a diversity of operational challenges. The application of the generic model to T2D analyses application of the model in long term service operations in which primary care plays an important role. Application to health service provisioning for patients suffering from stroke concerns acute and time sensitive operations which are mostly provided in hospitals. The application to health services for Hip OA addresses elective health service processes which typically start with conservative care for pain management, and almost always end in elective surgery.

The empirical case studies address the following research question:

5) Do the models and instances facilitate descriptions of provider networks for the different conditions T2D, Stroke, and Hip OA, in particular with regard to the relationships between operations and outcomes?
6) Does analysis of the instances and models advance the evidence base on health service operations in regional provider networks for T2D, Stroke, and Hip OA?

Research Methods

A mix of activities has been employed to realize the purpose of this research. This includes a systematic literature review, conceptual modeling, development of disease specific operational models, data collection and processing for health service networks, development of disease specific surveys, development of an analysis framework, statistical analysis, and expert panels. The systematic review is performed to answer research questions 1-2, which reviews the state of the art, central issues, and shortcomings regarding the use of operational models. A generic methodology for modelling and analysis of health services operations has subsequently been developed using knowledge from operations management and outcome research and lessons learned from the review. This methodological development regards research questions 3-5.

The methodology rests on three pillars: a generic modelling framework, disease models, and region instances. We will use a regional T2D health service network to illustrate specification of generic model to a disease and instantiation of a disease model to region instances. To answer research question 6 and corresponding sub-questions per disease, three empirical case studies will be conducted.

From a methodological viewpoint, the advancement of evidence in health services management differs essentially from the advancement of evidence in medicine. In medicine, evidence is predominantly based on experimental research designs, in particular randomized control trials [27]. Setting up and evaluating controlled trials as a design for interventions in health service operations in a network however brings about particular difficulties. Firstly, it is often impractical or practically undesirable to conduct an experiment with an intervention and a control group regarding health service operations in a network. Secondly, it is difficult to control a health services network during a managerial intervention for other contextual or managerial changes, which makes it harder to attribute effects and weakens the internal validity [19].

A natural alternative to experimental studies in a single service provider network – which consider a single context - is to conduct an experimental study which includes multiple networks. In so far as the network forms the context, this facilitates taking context into account in the analysis. By including sufficiently many networks, the significance of network context characteristics can then be quantitatively analysed. In fact, such a design implies that in addition to the patient (and the provider), the health service provider network forms a separate unit of analysis. The practical feasibility of such a design is limited as it requires recruiting a sufficiently large number of health service provider networks which commit to a controlled experiment. Often research designs have therefore limited the number of contexts, and/or have chosen an observational design rather than an experimental design. Indeed, empirical research in this area mostly depends on observational or comparative case studies [28, 29].

The empirical studies presented here are observational studies of six networks. For six regional provider networks and for the three conditions T2D, stroke, and hip OA the research regards outcomes in relation to service operations. The number of networks involved prohibits reaching statistically significant results when considering data at the network level, and hence limits external validity of the results (more so as the data collection was not equally successful in all regions and for each disease). Hence, the contribution to developing an evidence base of health service operations for these conditions is to create a proof of concept and to initiate the evidence base, rather than to establish it.

Provider information systems and surveys will be used as data sources. Data on service operations and use are partly at the network level and hence cannot be analysed at the patient level. Data for outcomes, behaviour, as well as additional data on operations, are collected via surveys and can be statistically analysed using patient level data.

Managed Outcomes Project and study design

This thesis is based on the EU FP7 Managed Outcomes project [18]. Managed Outcomes studied healthcare practices in six EU countries: Finland, Germany, Greece, The Netherlands, Spain and United Kingdom according to the study design presented in Figure 1-2. This project views and assesses health services taking an operations management perspective and demand based approach, and takes patient centred outcomes into perspective. The project aimed to develop modelling and an analysis approach replicable for diseases and regions to provide a basis to enhance better analysis and operational decision making in regional provider networks. The key contribution of the project is to develop a generic methodology for modelling health services which is required for comparing practices of health services in a standard manner for diseases and regions.

The selection of diseases and case countries, the demarcation of each study, and the research design of this PhD research are imposed by the Managed Outcomes project. The four diseases selected in advance in the context of Managed Outcomes are T2D, Stroke, Hip OA care, and Dementia. The data collection for the condition Dementia didn't allow analysis using the framework and methods presented in this thesis. Figure 1-3 presents an overall design of the analyses presented in this thesis.

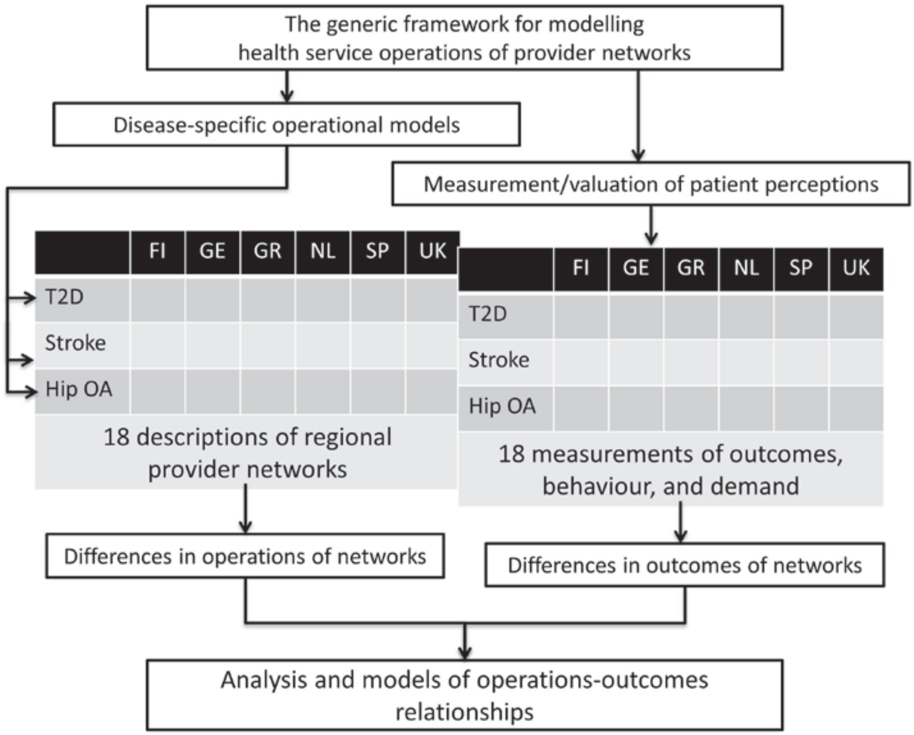

Figure 1-2 Managed Outcomes study design

Outline of thesis

The outline of the thesis is given in Figure 1-3. Chapter 1 presents an introduction to the thesis research on the relationships between health service operations and outcomes. In Chapter 2 we present a systematic literature review on the use of generic operational models for health service operations. This chapter summarizes the state of the art of health service operational models and contributions made to advance the evidence base on operational modelling. Chapter 3 is concerned with developing a generic modelling and analysis methodology for operations of provider networks. The methodological framework is illustrated using a regional instance in one of the case study regions. The subsequent three chapters 4-6 present the results of applying the generic framework to T2D, stroke and hip OA in six European countries. Chapter 7 first compares the application of the research framework for the three health conditions investigated, and presents the conclusions and reflections on the reuse of framework. Furthermore, we offer suggestions for future research from lessons learned from our systematic review, the methodology development of a generic framework for modelling provider networks and evaluating their performance, and from the three applications of the framework for T2D, stroke and hip OA.

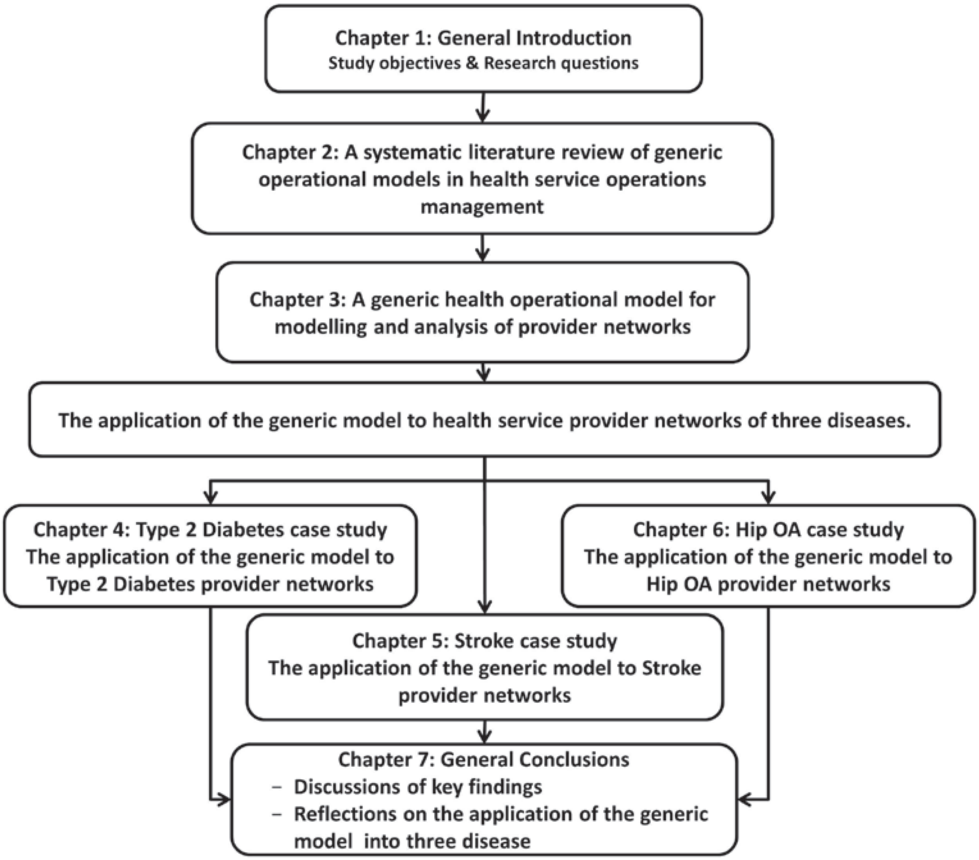

Figure 1-3 Thesis structure

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Chapter 2

Generic Operational Models in Health Service Operations Management: A Systematic Review

This chapter was published:

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Abstract

The area of Health Services Operations Management has received considerable attention in scientific literature over the past decades. Numerous articles have appeared in health services operations management literature in which models of health operations are used. In this paper we review this wide body of literature with the aim of synthesizing evidence on application of generic operational models in health services. A generic operational model is defined as a formal description of operations performed to deliver a health service that is applicable in a wide range of health service delivery settings. The systematic review of the literature that forms the basis of our research synthesis includes peer reviewed publications from business management databases (SCOPUS) as well as medical databases (Pubmed). Our search resulted in more than 4000 recent papers of which 116 papers met the inclusion criteria. This paper reports our synthesis from the included papers on four main questions: 1) why are models used? 2) what is modeled? 3) what models are used and how are they developed? 4) what are the achievements? Our systematic review reveals that few papers report achievements which qualify as empirical evidence to guide the application of operational models for health services. Nevertheless, the synthesis leads to an initial framework for operational modeling in health services to guide further research.

Keywords: Healthcare, Operations, Modeling, Review, Evidence

Introduction

Over the last centuries health service operations have progressed continuously as medical sciences and technologies have progressed and the health service demands and expectations of populations and individuals changed [1]. Health service operations have become considerably more complex, and so have the corresponding operations management issues for which societies are urgently seeking solutions around the globe [2].

Operational models can contribute to adapting and improving health service provisioning in such complex service systems[3]. Operational models form the lingua franca in which problems arising in the design, operation and improvement of health services can be generally formulated and addressed and on which solution methods can be based.

We define an operational model for health services as a formal description of operations performed to deliver a health service and with the purpose of facilitating operational (as opposed to strategic or tactical) decision making. An operational model describes operations which make use of resources in response to a demand of a patient. The value of the service lies in the health outcomes obtained and the evaluations of the service experiences.

Examples of formal descriptions of operations are process flow charts, care pathways, mathematical models or simulation models. Because the definition requires that the model facilitates operational decision making, the formal description must capture the service operations in all detail required to be taken into consideration for operational decision making. Based on the scientific communities which have considered operational modeling in health services, an initial categorization of such models can be as follows:

- General (service) operations models which are applied in health services such as i) (descriptive models) process flowcharting, service blue printing, activity modeling, business process modeling, simulation models), and ii) (analytical models) queuing model, Markov model, mathematical programming.
- Models from health services research which include clinical guidelines, clinical pathways, clinical paths, critical paths, care pathways, patient journeys.

We now briefly address genericity. The terms generic and specific models are defined based on common understanding and a prior study by Fletcher et al. [4]. From the perspective of model genericity, we distinguish models into i) specific models which are used to model a single provider within a single disease chain; and ii) generic models which apply across multiple providers within a single disease chain, or across multiple providers in multiple disease chains. More practically, we view a model presented in scientific literature to be specific if it is regards a single case study without presenting results that are valid beyond the case study, e.g. apply to other cases and/or contribute to theory. In this context, we recall that earlier reviews established in various ways that many specific models have been reported in the scientific literature, but with little synthesis and with few papers that present more generic models which are generalizable across multiple diseases or settings [4]. The disease-oriented structuring of the medical profession is a possible driving force underlying applied operations management research, which has its own share in the specific nature of the prevailing literature.

Using these above generic modeling techniques, researchers have actively developed generic health service operational models and solved many commonly encountered problems in health operations management (see[4]). This has however not silenced the many laymen, professionals, managers and researchers who state that health services are inefficient and/or ineffective [5]. This raises the question whether existing scientific methods and models fall short of enabling practical improvements for today's health service operations challenges or, alternatively, whether practitioners fail to identify and apply these methods and methods? In this paper, we therefore explore if and how scientific contributions to health service operations modeling have contributed to improving the complex health service systems. The aim of our research is to review state of the art scientific literature on generic health service operations models and modeling techniques and to structure existing evidence on the contributions generic models have made to the practice of todays complex health service systems. More specifically we review the evidence on: i) the purposes of modeling ii) the services and service operations which have been modeled iii) the modeling techniques which have been applied iv) the achievements, in particular regarding implementation. Subsequently, we investigate the interrelationships among these topics of interest.

In this review, we chose to adopt an approach to analyzing and presenting research results, which is quite novel to operations management. The novelty relates to the application of the evidence based Healthcare Management paradigm in Health Service Operations Management. There is to our knowledge no such study that synthesizes state of the art scientific literature in health services operations management using the evidence base approach. Our research can therefore be viewed to parallel the development of evidence based research in health services research [6, 7]. Our research also answers recent calls for evidence based management [8]. The novelty of our research also relates to the approach that we have adopted to analyze this study results. As the limited number of papers make it not feasible to apply the methodology of evidence based healthcare (e.g., meta-analysis to synthesize evidences), we have developed a pragmatic approach to classify evidences and to conclude evidence bases. We believe that this systematic novel approach has led to new answers and insights. In our view it contributes to understanding and dissemination of existing research and results, and to strengthen the evidence base for health service operations management. A reflection on the methods and findings is provided in the discussion section.

Study purpose

We have conducted a systematic review using an explorative approach to providing a research synthesis [9]. To provide a starting point for an empirically relevant theoretical structure of generic health service operational models, a research synthesis of a large number of primary articles is conducted through a literature review [10].

In order to define the type of evidences needed for the study objectives we build upon Kovner's work in evidence based management [8] and translate the research objectives into four dimensions:

i) 'why models are used' addresses the purpose of study.

ii) 'what is modeled' addresses the application area of the model (patient group modeled, process modeled, setting modeled, resources included).
iii) 'How are models developed' addresses model objective, modeling method, and modeling language or software.
iv) 'What are the achievements' addresses the research findings, and whether they have contributed to practice, e.g. have been implemented, and/or contributed to health service operations management theory.

We start by noticing that studies considering the relationships between these dimensions are limited to one dimension or to a specific set of models [11] or specific settings (e.g. hospitals) [3]. Brailsford et al. [11] investigated the relationship between the functional area of simulation models and the types of model used. In the same vein we investigate relationships among the aforementioned dimensions. By developing an ordinal domain of values for each of the dimensions, we explore relationships between domain values. An example of a most extensive possible relationship for which the synthesis might provide evidence can be read as: 'studies which use model X for purpose Y in patient group Z are more likely to achieve result V in practice'. Notice that this relationship claims generalizability across a wide variety of healthcare settings, and must therefore be based on studies in which models are generic and have external validity [12]. As specific models lack external validity, therefore our research synthesis is restricted to generic models.

Previous research

Various authors have discussed operational models for health service operations in a general manner prior to our work. These general reviews complement the many applications and case studies which have been reported in literature. Some of these studies will be reported in subsequent sections. Their nature and number have been addressed by most review papers that have been published up to now. Wilson [13] already reports over two hundred simulation case studies in health care. Fone et al. [14] critically review the use of simulation modeling in population health and healthcare delivery and call for further research to assess the value of modeling. Sobolev et al. [15] review the use of computer simulation in modeling patient flow in surgical care. They report limited understanding of value of simulation in healthcare management. Brailsford et al. [11] report more than thousand papers on simulation in the emergency department alone, while Günal et al. [16] report that the number of papers appearing on simulation studies in health care has developed from around one hundred yearly in 2000, to around four hundred yearly since 2005. They conclude that most studies are case specific, "that there is no general sense of the literature moving forwards," and that the studies "rarely lead to generalisable insights or to general theory." Although Wilson (1981) concluded more than 30 years ago that less than ten percent of the case studies have led to implementation, thousands of case studies have been published since then, which don't consider practical implementation [13]. Harper forms an exception [17]. The general framework for operational modeling of hospital resources proposed therein has been successfully applied for specific case instances. Contrary to the aim of our work, however, his framework primarily addresses strategic and tactical capacity planning and therefore lacks details of operational processes.

A second shortcoming observed by Günal et al. [16] and Sobolev et al. [15] is that many studies consider tightly bounded elements of the complex health service system, thus potentially leading to suboptimisation. Moreover, they observe that re-use of reported models appears to be non-existing. It appears that the evidence base on the appropriate use of models and methods has not developed systematically. These observations imply that earlier conclusions, drawn by Jun et al. [18] and Cayirli and Veral [19] who already call for less specific and more wide ranging and comprehensive contributions, have had little effect. The lack of generalized applicability appears to be persistent.

Cayirli and Veral who consider operational planning problems (scheduling problems) in outpatient planning, provide a thorough discussion of the objectives considered by the various authors, most of which regard responsiveness or efficiency [19]. Equity (fairness) is also considered by some authors but effectiveness in terms of health outcomes or patient experiences is never addressed. They too conclude that most of the reviewed work considers single service activity models and concentrates on such issues as arrival patterns, no-shows, walk-in customers versus appointment taking, service duration distributions and lateness, rather than on the service operations processes.

Vanberkel et al. by contrast, consider operation research models which are less tightly bounded and address multiple departments [20]. Their extensive research addresses hospital planning issues, distinguished by service type (emergency, surgical, inpatient, outpatient, diagnostics & pharmacy, geriatrics and mental health care) and they explicitly address the role of clinical pathways for the patient flows involved. The emphasis of their study lies on operations research models and solution techniques, and they conclude that many researchers have had difficulties capturing the variability of health service processes, especially so because of lack of standardization and information. Once again it appears that the majority of the reviewed work adds case studies as opposed to advancing theory and evidence.

Fletcher & Worthington conceptualize the spectrum of genericity of models in a modeling framework, based on transportability and abstraction [21]. They distinguish four levels of genericity, ranging from a specific model (single provider, single service chain, single industry) to a generic model (multiple providers, single service chain, single industry), a generic framework (multiple providers, multiple service chains, single industry) and a generic principle (multiple providers, multiple service chains, multiple industries). Their review on specific versus generic models in emergency care illustrates that there is much more research on specific models.

The outline of this paper is now as follows. We first describes the methodology followed to search, select and review scientific literature. In section Results we report the results. Section Discussion provides discussions, conclusions, and recommendations.

Methodology

This research is limited to what is commonly referred to in operations management as the primary operations: the health service operations which directly contribute to the patient health and/or experience. These primary operations are sometimes also referred to as core functions that lead to existence of the health organization and serve their missions [22, 23] and may include prevention, diagnosis, treatment, and rehabilitation processes [24]. Let it be explicitly noted that the research is not limited to primary care; it considers all health service operations which directly contribute to health outcomes and/or health service experiences. The research excludes secondary processes such as finance, HR, et cetera.

Search strategy and search terms

A preliminary literature search was carried out with the aim of finding previously performed systematic reviews and assessing the volume of relevant papers for this study. The search strategy for this preliminary search was formulated on the basis of the study objective and the conceptualization of the operational model. Preliminary search terms included: 'health operational model' and 'health operations management model'. This search resulted in very modest numbers of relevant studies. Consequently, a new strategy was developed which relied on two threads. The first (and the primary) thread is to search scientific management literature, especially operations management databases using more specific search terms (Table 2-1).

We searched in the SCOPUS database, which is considered to contain most relevant literature [25]. Furthermore, SCOPUS covers a wider journal range compared with the Web of Science. For citation analysis SCOPUS provides 20% more coverage than Web of Science. However, as far as reuse of models is considered, we did not count citation in the database (See Table 2-2 for inclusion criteria) [26]. Based on our earlier findings and snowballing, we concluded that searching through the SCOPUS database delivered the far majority of relevant published articles.

Table 2-1 provides the search terms we have formulated using an initial set of terms which we iteratively extended upon discussing the findings. The search terms were constructed by appropriately combining modeling keywords, specifying operational models, with general terms as health, care, hospital, and nursing.

The second thread has been to search for health service operational models using medical sources, in particular Pubmed using MeSH Terms. This strategy yielded a large number of irrelevant studies. This problem is also seen by other health operations management researchers (See [3]) who found that the MeSH Terms are inappropriate for searching healthcare management topics). Furthermore, the list of MeSH Term was found incomplete in searching the operational models. Therefore, we adapted to search Pubmed using general terms such as 'service operations' and other terms presented in Table 2-1. We modified this set to the Pubmed data set so as to best capture the most relevant operational models appearing in medical literature. The search terms and strategy presented in Table 2-1 is the result of iterative improvement and discussion among the authors to validate the search strategy.

Paper selection

The systematic process of paper selection has been as follows. Abstracts were selected based on title and keywords. Two reviewers independently selected the abstracts and then results were compared. If both reviewers had selected a paper, it was accepted. In case of doubt the decision to accept was based on the full text. The paper selection process is presented in Figure 2-1. A screening protocol (Table 2-2) was used to guide the reviewers through the paper selection process.

Table 2-1 List of search terms and number of hits

Source	Keywords	Hits
SCOPUS	"operational model" AND (health OR care OR hospital OR nursing) (1)	130
	"clinical guideline" AND (model OR language)	812
	"clinical pathway" AND (model OR language)	700
	"clinical path" AND (model OR language)	30
	"critical path" AND (model OR language) AND (1)	61
	"care pathway" AND (model OR language)	179
	(Patient OR user) AND journey AND (model OR language)	354
	“Process flowchart” AND (1)	8
	"Activity modeling" AND (1)	18
	“Process modeling” AND (1)	124
	"business process" AND (model OR modeling) AND (1)	214
	"Business process reengineering" AND (model OR language) AND (1)	15
	("Service blueprinting" OR “service blueprint”) AND (1)	4
	("Value stream mapping" OR "Value stream map") AND (1)	20
	(queuing OR queuing OR queue) AND (model OR theory OR network) " AND (1)	253
	simulation AND (operations OR operation OR operational) AND (model OR modeling OR modeling) AND (1)	619
	(“patient flow” OR “flow of patient”) AND (model OR modeling OR modeling)	215
	Markov and (chain OR model OR network OR matrix OR process) AND (operation OR operations OR operational) AND (health OR care OR hospital OR nursing)	60
PubMed	“Service operation” OR “Service operations”	96
	"operation model" OR "operations model" OR “operational model”	235
	Total number of hits	4147

The criteria under A, B and C are conjunctive. The criteria under D are disjunctive. Table 2-2 shows that we excluded papers which consider models restricted to medical decision making. In the end 116 papers were selected for information extraction and analysis which are presented online in an additional file at the ResearchGate.

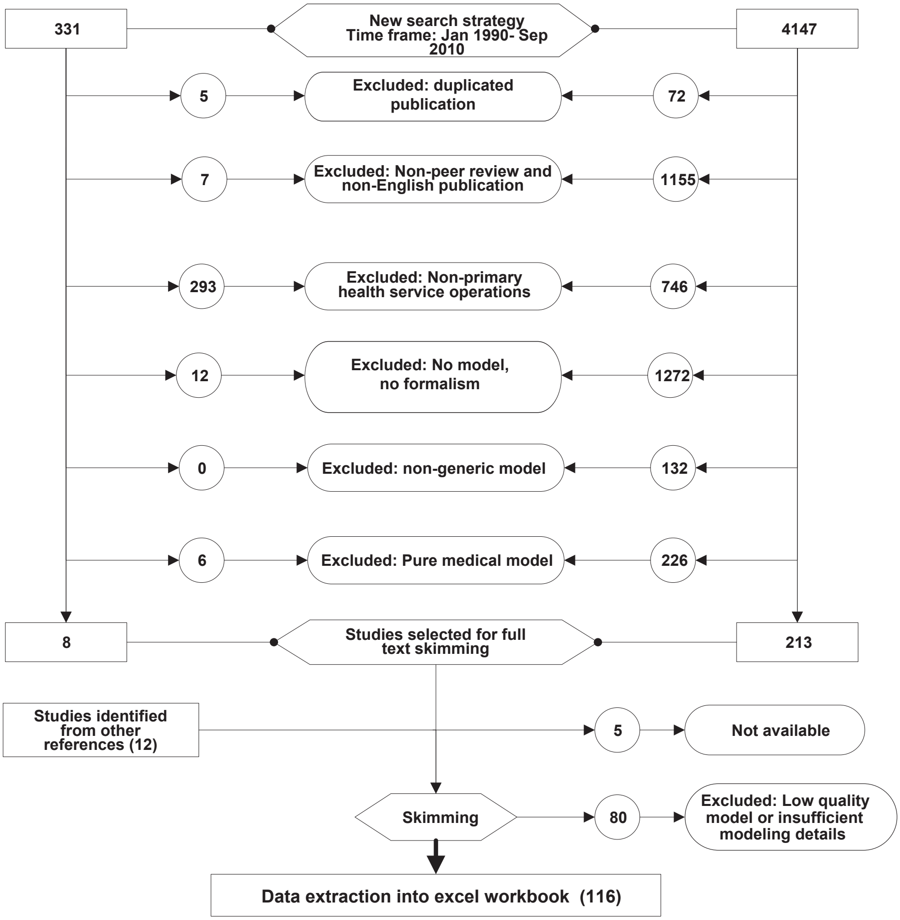

Figure 2-1 Paper selection process

Information extraction and analysis

Having recorded author ID, title, publication date, and country of study we extracted data on the dimensions of models: study purpose, application areas, method of modeling, and achievements. To record the information a spreadsheet was developed and for each paper one sheet was used. In the extraction sheets the reported information from the papers conforms the text in the article. Meanwhile efforts were made to complete the description of the papers by adding categories. Then scoring was performed to extract information from the summary sheets, based on a classification of the descriptions (values) found in an information category. For most information categories, the values can be expressed as nouns, e.g. 'Hospital' is a value for the category 'Setting'. For the categories 'Study purpose', 'Model objective', and 'Result' the values are in principle described by a verb and a noun, e.g. 'Improve performance'. Thus, the description addresses what has been done and on which topic. To condense the information into sets of larger cardinalities, values were grouped when this could be done meaningfully [27].

The values for the final two categories 'Implementation' and 'Advancing knowledge' have been logically specified by the authors.

Table 2-2 Screening protocol

Screening questions		Yes	No
A.	**General questions**	Continue	Discard
	- Is the paper written in English?		
	- Is the paper published in a peer-reviewed journal?		
	- Does it concern primary health service operations?		
	- Is the paper not restricted to medical decision making?		
B.	**Does the paper represent a health operational model?**		
	- Is there a model of one or more primary health service operations?		
	- Are the models operational and is significant model information (detail) presented in the paper for further analysis?		
C.	**Assessment of how models are developed?**		
	- Is the technique a generic technique such as the techniques in the predefined list of operational models?		
	- Is the model a formal description?		
	- Is there a precise and unambiguous description of the model?		
D.	**Check the generic character of models**		
	- Is the model applied to multiple providers?		
	- Is the model a reuse of a previous model?		
	- Is the model developed by a healthcare modeling framework within a package software/language?		
	- If the model is not built by a dedicated health service software or language, is adaptation or development of the software/language explained?		

Results

Having extracted the information from the included papers we analyzed results to answer our research questions. We start with providing some information for the study objectives based on straightforward analysis of frequency tables. Then we present a selection of cross-tables that will be used to provide insight into dimensions of operational models and investigate possible remarkable relations between dimensions. The detailed data and results are available at online additional file at the ResearchGate. The data file consists of a master table containing a list of all values for each paper. This will enable a verification and/or reproduction of the results.

Descriptive information

The presentation of results will be guided by the four dimensions presented in the research objectives, thus providing insight into: 1) why models are used, 2) what is modeled, 3) how models are developed, and 4) what is achieved with the modeling.

Why models are used and what is modeled?

To provide more insight into the aspects of modeling that have to do with the questions of why models are used and what is actually modeled, we will present results on the purpose of the modeling (Table 2-3) and application areas (Table 2-4) including the patient group modeled, the process modeled, the setting modeled, and the resources modeled.

Table 2-3 Why models are used

No.	Value	N	%
1	Demonstrating use of/develop model or modelling technique	24	21
2	Estimate use of resources/demand and plan capacity	22	19
3	Describe patient flow, process or care delivery	21	18
4	Evaluate performance/efficiency / evaluate intervention	16	14
5	Describe/aid process of redesign	9	8
6	Develop/implement clinical guideline or guideline system	8	7
7	Identify bottlenecks	8	7
8	Aid scheduling	5	4
9	Other	3	3

If we look at the purpose of modeling, almost three quarters of the papers fall in four main categories as are ranked from number one to four in Table 2-3. Viewing the list of research purposes, we firstly note that more than one third of the papers have a descriptive objective such as to describe a patient flow or to show that a technique can be used. The studies which have as purpose to improve health service operations typically regard the efficiency, planning and modeling of resource use and processes. This contrasts quite sharply with a purpose common to most health services research namely to improve health outcomes. We found that outcomes, which is defined as “the effects of care on the health status of patients and populations” [28] and the quality of life of patients [29], did not qualify as a category of purposes on the basis of the included papers.

The most frequently modeled patient groups are elective patients, emergency patients, and chronic patients. The most frequently modeled processes are “treatment processes”, which are distinguished into acute and plannable processes. All emergency processes and urgent care processes are categorized under the heading ‘acute treatment’. Non-emergent and non-urgent care processes that cannot be under other headings are categorized under the heading ‘plannable treatment’. The majority of the included papers is focused at suborganisational level, i.e., units or clinics (more than half of the modeled settings). Considering the process, most of the included papers study processes for patient groups who demand cure, whereas prevention and chronic diseases appear much less frequent. Likewise regional health systems and long term care settings are under-researched [30].

Table 2-4 What is modeled

Dimensions	Value	N	%
Patient group	Elective patients	33	31
	Emergency patients	28	27
	Chronic and co-morbid	20	19
	Intensive care	14	13
	Public health care and prevention	6	6
	Other	4	4
Process	Acute treatment	45	41
	Plannable treatment	35	32
	Long term care	13	12
	Diagnosis	10	9
	Prevention	7	6
Setting	Unit/department/ clinic/centre	63	54
	Hospital	26	22
	Process and program	16	14
	Regional health system	6	5
	Long term care setting	5	4
Resource	Bed	34	41
	Staff	28	34
	Health services facility	16	20
	Other	4	5

How are models developed?

To provide insight into method of modeling we present results on the technique used, the software or language used to build the model, and the objective used in the model (Table 2-5).

If we consider the technique that is used for modeling, clearly simulation is most popular, followed by queuing and graphical models. A graphical model is defined as a representation using grammar of predefined symbols of health services operations. In this study graphical models embrace process models or maps, process flow models, and value stream maps. In terms of software or modeling language used, there is a relationship, obviously, between technique and software/language. The objective that is used in the model shows a larger range of and wide spread over options. Note that as has been observed and discussed when considering the study purposes, description is often mentioned as primary objective and that improving health outcomes is rarely an objective used in the modeling.

Table 2-5 How are models developed

Dimensions	Value	N	%
Technique	Simulation	42	36
	Queuing model	30	26
	Graphical model	20	17
	Clinical guideline or pathway	8	7
	Markov model	7	6
	Other mathematical modelling methods	5	4
	Other	4	3
Software/ language	Generic simulation software	26	32
	Graphic notation system	14	17
	Mathematical modelling language	14	17
	Healthcare-specific simulation software	9	11
	Healthcare-specific decision support system	5	6
	Spreadsheet software	5	6
	Others	9	11
Model's Objective	Improve efficiency/improve throughput	19	16
	Waiting time reduction	18	16
	Planning	16	14
	General optimization	14	12
	General descriptive model	11	9
	Predict/forecast	9	8
	Patient flow description	8	7
	Guideline development	4	3
	Improve health outcomes	3	3
	Other	14	12

What are the achievements of modeling?

To get a clearer view on what the modeling has achieved, we will present information on the type of results achieved, the level of implementation of models (Table 2-6), and accumulation of evidence (Table 2-7). Most models achieve results that can be captured under 'increased understanding' and 'improving operations'. In our review, very small percentage of the studies reported implementation and only one tenth of studies reported implementation and evaluation of effects after implementation. In addition, we observe that very few papers report implementation (see Table 2-3)–although doubled since Wilson [13]. From the total set of included papers, only one tenth of studies reported implementation and evaluation of effects after implementation.

Results on how models contribute to the advancement of research results are presented in Table 2-7. We have made a distinction between:

- using empirical results from previous research that was implemented, for instance data on arrival distributions;

- using theoretical results from previous research, i.e., using a mathematical proposition or proof or framework published previously;
- producing empirical results, i.e., providing an evaluation of the empirical results obtained after implementation;
- producing theoretical results, i.e., providing a mathematical proposition of proof or framework or language which can be assumed to have value and validity beyond the scope of a specific model and/or single case study.

To derive this information from the papers we looked especially at the methodology section and the introduction section and in addition have checked whether the authors stated explicitly that they made use of empirical or theoretical results from other authors.

Table 2-6 What are the achievements of modeling

Dimensions	Value	N	%
Result	Understand operations	21	19
	Modeling improvement	16	14
	Choice	12	11
	Performance improvement	11	10
	Resource requirement specification	10	9
	Influential factor assessment	9	8
	(optimal) redesign	7	6
	Insight	7	6
	Prediction/Planning decision	7	6
	Medical model development	4	4
	Others	7	6
Implementation	No Implementation	99	85
	Implementation; Results evaluated	10	9
	Implementation; Results not evaluated	7	6

The use of theoretical results is more frequent than the use of empirical results; 23% of the papers report having used theoretical results from papers published by other researchers. Producing theoretical results that can be used by others is the most common contribution that we found in our review.

Table 2-7 Use and produce of research results

Type of results		Use results		Produce results	
		N	%	N	%
Empirical results	Yes	2	2	17	15
	No	85	98	99	85
Theoretical results	Yes	26	23	38	33
	No	89	77	77	67

Relational information

Having presented the evidences on the four main dimensions of operational models (purpose, areas of application, methods and achievements), we now turn to the relationships between the dimensions. The analysis tries to identify multidimensional relationships of the form 'studies which use model X for purpose Y in patient group Z are more likely to achieve result V'. However, the data directed us to the less ambitious exploration of two–dimensional relations.

We have developed contingency tables to assess the relationships between dimensions and to illustrate remarkable patterns. The columns of the tables correspond to the values of (a category) of one dimension, and the rows to the value of another, potentially related category from another dimension. The observed values of the cells of the tables are the number of papers which are categorized as having the category values corresponding to the respective columns and rows.

If there is no relationship between the categories, the distribution of the observed values should be independent of the one dimensional frequencies f_{row}, f_{column} of the values corresponding to the rows and columns. We therefore define for every cell of a table the expected value as the number of papers that results from assuming there are no dependencies between the frequencies of the category values: *(f_{row} * f_{column})/(# papers included)*. We define a cell as remarkable when the observed value deviates substantially from the expected value. As the values of the fields fail to meet the criteria of a formal statistical test such as the chi-square test [31], we pragmatically define a cell as remarkable if the absolute difference between the observed value and the expected value is more than two, and the fraction of observed value and the expected value is more than 1.5 or less than 0.5 (i.e. if the expected value deviates by more than 50%). We say a combination of category values corresponding to a cell is 'remarkably frequent' if the fraction exceeds 1.5 and we say it is 'remarkably infrequent' if the fraction is less than 0.5. Below, the remarkable cells are colored. For further checks on how the analysis is conducted we refer readers to online additional file at the ResearchGate.

We will not provide contingency tables for all relationships but present those with remarkable cells that we judge to be of interest. A summary of remarkable relationships is provided for those dimensions that have not been encompassed in contingency tables (See Table 2-8).

Purpose of modeling and modeling technique

Table 2-9 illustrates the relationship between the purpose of modeling and the technique used for modeling. Several cells are remarkable. Graphical models are used remarkably frequent for the purpose of 'demonstrating use of/develop model or modeling technique' and for the purpose of 'describe patient flow, process or care delivery' [32, 33]. Queuing models are used remarkably frequent for the purpose of 'estimate use of resource/demand and plan capacity' (35). Simulation is used remarkable frequently for the purpose 'evaluate performance/efficiency/intervention' [34, 35].

Table 2-8 Summary of key relationship between operational models' dimensions

Dimensions	Remarkable relationships
Purpose and process	Demonstrate use of/develop model is a remarkably frequent purpose for prevention process.
	Estimate use of resource/demand and plan capacity is remarkably frequent purpose for care process.
Purpose and technique	See Table 2-9
Purpose and type of result	See Table 2-9
Technique and process	Use of Markov models to model care process is remarkably frequent.
	Use of graphical models to model prevention process is remarkably frequent.
	Use of simulation to model care process is remarkably infrequent.
Technique and setting	See Table 2-10
Resource and technique	See Table 2-10
Type of result and technique	See Table 2-10
Process and implementation	Implementation is remarkably frequent in treatment processes that can be planned.
	Implementation is remarkably frequent in diagnosis processes.
Type of result and implementation	Implementation is remarkably frequent in modeling improvement.
	Implementation is remarkably frequent in resource requirement specification.
Setting and implementation	Implementation is remarkably frequent in hospital settings.
Technique and implementation	See Table 2-10
Technique and advancing theoretical knowledge	See Table 2-10

Purpose of modeling and result achieved

Table 2-9 also highlights the relationships between study purpose and result. We mention some of the remarkably frequent patterns as examples. Modeling improvement and resource requirement specification occur remarkably frequent as results for the purpose 'describe patient flow, process or care process' [36]. 'Estimate use of resources and capacity planning' occurs remarkably frequent as results in combination with the purpose 'resource requirement specification'[37].

Technique of modeling and application areas

The relationship between modeling technique and application areas, i.e. setting and resource, are presented in Table 2-10. Simulation techniques appear remarkably infrequently for the setting which takes a hospital as unit of analysis, but rather appear to address smaller organizational entities. Queuing models occur remarkably frequently as technique in a hospital setting.

Table 2-9 Relationship between purpose of models and technique of modelling and results

	Purpose of models								
	Demonstrate use of/develop model or modeling technique	Describe patient flow, process or care delivery	Estimate use of resources/ demand and plan capacity	Evaluate performance/ efficiency/ Evaluate intervention	Describe/ aid process of redesign	Identify bottle-necks	Develop/ implement clinical guideline	Aid sche-duling	Other
Technique									
Simulation	8	6	7	9	4	4	1	1	2
Queuing model	5	4	11	4	2	3		1	
Graphical model	7	7		1	1	1	1	1	1
Clinical guideline or pathway	2						6		
Markov model	1	3	1		1			1	
Other mathematical modelling methods			2	2				1	
Other	1	1	1		1				
Results									
Understand operations	5	5	5	3	1	2			
Modeling improvement	6	5	1	2			1	1	
Choice	3	2	2	1	1	1		2	
Performance improvement		2	3	2	2	1		1	
Resource requirement specification		4	4		1			1	
Influential factor assessment	1		3	1	1	1			2
Insight	1		2	1		3			
(Optimal) redesign	2	1		3	1				
Prediction/planning decision	1	1	1	1	1		1		1
Medical model development							4		
Others	2	1		2	1		1		

Remarkably frequent (light shading) | Remarkably infrequent (dark shading)

Table 2-10 Relationship between technique of modelling and other dimensions

	Modeling technique						
	Simulation	Queuing model	Graphical model	Clinical guideline or pathway	Markov model	Other mathematical modelling methods	Other
Settings							
Unit/department/clinic/centre	29	18	7	4	3	1	1
Hospital	5	9	4	4	2	1	1
Process and program	4	2	8			1	1
Regional health system	3				1	1	1
Long term setting	1	1	1		1	1	
Resources							
Bed	9	16	2		5	2	
Staff	13	5	6	3		1	
Health service facility	7	3	2		2	1	1
Other	1	1	1	1			
Results							
Understand operations	7	6	6		1	1	
Modelling improvement	4	2	4	2	1	1	2
Choice	7	2		1	2		
Performance improvement	4	6	1				
Resource requirement specification	2	5	1		1	1	
Influential factor assessment	5	3	1				
(Optimal) redesign	3	2	1				1
Insight	4	1	2				
Prediction/Planning decision	5	1				1	
Medical model development				4			
Others	1	1	1	1	2	1	

Table 2-10 Relationship between technique of modelling and other dimensions (continued)

	Modeling technique						
	Simulation	Queuing model	Graphical model	Clinical guideline or pathway	Markov model	Other mathematical modelling methods	Other
Implementation							
Implementation; Results Evaluated	3	5	2				
Implementation; Results Not Evaluated	1	3	2	1			
No Implementation	38	22	16	7	7	5	4
Produce theoretical results							
No	39	12	17	4	2		3
Yes	3	17	3	4	5	5	1

Remarkably frequent Remarkably infrequent

Technique of modeling and result achieved

In many of the included studies, the resources are explicitly taken into consideration, often in terms of their capacity. Table 2-10 provides information on relationships between the resources modeled and the modeling technique used. It shows that the resource beds occur remarkably frequently in relation to queuing models and Markov models.

The relationship between modeling technique and results are presented in Table 2-10. It appears that graphical models appear remarkably frequently in combination with the result understand operations and simulation with tactical results such as 'choice', and 'prediction or planning decision'. All frequencies are however relatively small and even the remarkable values are relatively modest.

The final two rows of Table 2-10 provide indications on the models types with respect to producing and using theoretical results. The small number of papers which report evaluated implementation remarkably frequently concern studies in which queuing models have been applied – although queuing is not remarkably infrequent among the not implemented papers. We see that the mathematical approaches (queuing models, Markov models) remarkably frequently provide theoretical results.

It appears that there is little use and produce of research results by the descriptive models (graphical models, simulation models, guideline models) (Table 2-10). The analytical models (queuing models, Markov models, other mathematical models) appear to remarkably frequently produce theoretical results and queuing are remarkably frequently implemented (5 out of total 10 implemented models). Still, very few of them are being evaluated.

Discussion

This study is undertaken to synthesize literature on operational models for health service operations, considering various dimensions of the studies and models, and explores how these dimensions are interrelated.

Our research reveals that the majority of the peer reviewed published research had objectives regarding (the use of) models themselves, or to describe health service operations. Further, the majority of researches made use of straightforward descriptive models such as graphical models. Exploring (the use of) models or describing health service operations using straightforward models can only be positioned at one of the lower levels in the "hierarchy of evidence", and less so for specific models and single case studies [38]. This kind of research can gain significance when serving as a basis for subsequent research which advances theory or improves practical health service operations. This requires external validity of the results obtained, and future reuse of results. Our findings indicate that a modest number of the papers found in the search present results which have external validity - even among the included papers which are selected because of their genericity - and that reuse of previous results by the included papers is in turn quite limited.

Our results confirm the findings by Brailsford et al. [11], Günal and Pidd [16], and Fixsen et al. [39] that reporting of implementation of model results is quite limited. Implementation of operational improvements often leads to unexpected consequences in performance, in particular regarding health outcomes, and might even create havoc if changes did not work out as planned [40]. Consequently, researchers are called upon to provide convincing evidence when claiming that study findings yield positive practical consequences.

As the main purpose of health service operations is to improve health outcomes [41], one might expect that models for health service operations optimize or describe health outcomes. However, very few of the models in the papers included in the review consider health outcomes, be it in terms of normative objectives, as a constraint, or descriptively. As health services provisioning typically involves complex systems with many interdependencies, health outcomes cannot be assumed to remain unaffected by changes in health service operations which effect other measures such as efficiency or equity. Changes in capacities, processes, resources, planning, et cetera are reported to effect outcomes in many cases (e.g., [42–44]). Explicit inclusion of health outcomes in operational models for health services therefore appears an obvious ambition for future research.

Only nine percent of the included operational modeling researches addressed long term care or network settings of health services. Instead, the majority of operational modeling studies regards suborganisational units of analysis. Present health service priorities are typically life style and age related, and regard (chronic) diseases such as obesity, diabetes, dementia, cardiovascular diseases and mental disorders [45]. Therefore it can be advocated to shift the attention of health service operational modeling towards models which aim to contribute to improving outcomes of health service operations in long term care and network settings, which serve the chronically diseased and elderly.

A summary of key relationships found between the dimensions of operational models is presented in Table 2-11. The key findings in Table 2-11 are not qualified to be evidence based in the usual sense of relying on evidence from empirical evaluation. The findings use as evidence (remarkably frequent) combinations of modeling purposes, techniques, purposes and/or results as reported in scientific research on generic models for health service operations. As such, Table 2-11 synthesizes the expert opinion presented through the included peer reviewed papers. We hope it serves as a methodological aid for practitioners and researchers facing practical problems. Application of the framework may establish a basis for accumulation of theory and for practical implementation of model results. After being evaluated, such empirical implementation may in turn serve to develop an evidence base for operational modeling of health services. As pointed out by Walshe and Rundall [46] making such evidence accessible, by dissemination and further synthesis, will serve to reduce the unhealthy divide that currently exists between the research and practitioner communities in health care management. Researchers can change the course of the current flow of descriptive, specific case studies which yield limited advancement, while practical advancement is urgently called for by today's complex health service systems as argued in the introduction[47, 48].

Table 2-11 How operational models are used

	Models				
	Simulation	Queuing model	Graphical model	Markov model	Clinical Guideline
Purpose	Evaluate performance Evaluate efficiency Evaluate intervention	Estimate resource use Estimate demand Plan capacity	Demonstrate use of model Develop model Develop modeling language		Develop/implem ent clinical guideline or guideline system
Process			Prevention	Chronic care	
Setting	Unit Department Clinic Health center	Hospital	Process Program		Hospital
Resource		Beds	Staffs	Beds	
Result	Prediction Planning decision Choice	Resource requirement specification Performance improvement	Understanding operations		Medical model development

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Chapter 3

Modelling and Analysis Methodology for Evidence-Based Health Service Operations in Regional Provider Networks

This chapter is based on:

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Abstract

Health service operations management has developed considerably as a scientific discipline over the last decade, but the relationships between operations and outcomes are largely unexplored. Conversely, health sciences and outcome research have sought little connection with operations management. In this paper we propose a modelling framework which enables to systematically explore the relationship between operations and outcomes. The model refers to networks of health services providers (as opposed to the departmental or organisational perspective of service delivery) as suitable for many of today's most prevalent diseases. The basis of the framework is formed by a general model from which disease specific models can be derived. For specific cases, instances of regional networks can be created which include the health service users. In addition to the modelling framework we propose analysis methods to analyse how the operational models can explain outcomes. The models and analysis methods are illustrated using primary care networks for Type 2 Diabetes, using data from six European countries from the project Managed Outcomes which was funded by the European Union.

Keywords: Provider Networks, Health Service Operations, Models, Outcomes

Background

Health services provisioning for today's complex health demands requires efforts of a variety of health service professionals from various health service provider organizations. These professionals and provider organizations jointly establish networks to meet demands of a population of health service users living in a geographical region [1–3]. These networks may be implicitly defined as a collection of health service providers jointly visited by (a population of) health service users, and/or explicitly through collaborative relationships between the health service providers [4]. Together, the health services operations provided by the network to the health service users form a complex entity encompassing for instance services, resources, organizational structures [5] and (co-creating) behaviour [6, 7].

As especially the treatment of chronic and multi-morbid conditions relies on the joint performances of networks of health service providers and as these conditions permanently increase [8] there is a high societal urgency for investigating such networks. The well-known structure-process-outcome (SPO) model of Donabedian [9] represents a seminal paradigm regarding the effectiveness of treatments in health services research: the quality of outcomes depends on the quality of processes, and both depend on the quality of structures. The SPO model remains to be widely embraced and applied in practical settings for instance, by the Agency for Healthcare Research & Quality (AHRQ). Yet from a theoretical viewpoint the nature of the proposed relationships is at best partly understood. Specifically in relation to health service provider networks, Mahdavi et al recently concluded from a systematic review that scientific understanding of the relationships between operations and outcomes is in fact very limited [10]. Addressing this research gap poses new and challenging scientific questions, as will become clear in this paper.

A further limitation of the present scientific work in the area of health services operations management is that it lacks implementation and evaluation [10]. Moreover, several reviews point out that the little evaluation which has been done predominantly regards operations management in departments or organizations, instead of provider networks. As a result the evidence base of health service operations management in provider networks is in an early stage of development. This status contrasts the general developments in medicine and health sciences which has witnessed considerable adoption of evidence based approaches, i.e. "the judicious use of current best evidence in making decisions about the care of individual patients" [11, 12]. The majority of these researches, however, have focused on the medical processes, rather than the management of the service operations. Rousseau et al. has recently called for evidence based approaches to health services management and advocates the use of rigorous evaluation to synthesize an evidence base for effective health services provisioning [13].

From a methodological viewpoint, the advancement of evidence in health services management differs essentially from the advancement of evidence in medicine. In medicine, evidence is predominantly based on experimental research designs, in particular randomized control trials [14]. Setting up and evaluating controlled trials as a design for interventions in health service operations in a network however brings about particular difficulties. Firstly, it is often impractical or practically undesirable to conduct an experiment with an intervention and a control group regarding health service operations in a network. Secondly, it is difficult to control a health services network during a managerial intervention for other contextual or managerial changes, which makes it harder to attribute effects and weakens the internal validity. Thirdly, evidence indicates that interventions in the structures or processes of health service operations have different effects on outcomes in different contexts [15], and hence for different provider networks. This weakens the external validity of evaluation studies which solely address the intervention (and not the context), however rigorous the study design and protocol may be. Berwick points out how many studies have failed to regard local details, i.e. context which is essential to reach valid generalizable evidence, and advocates the use of techniques from the discipline of operations management. Van Aken formally describes the CIMO logic, which considers Context next to Intervention and seeks for Mechanisms which explain how Outcomes are influenced by both [16]. The CIMO logic belongs to a wider class of research techniques to explore the effect of interventions in health service operations on outcomes taking context into account.

A natural alternative to experimental studies in a single service provider network – which consider a single context - is to conduct multiple network studies. In so far as the network forms the context, context can then be explicitly differentiated. By including sufficiently many networks, the significance of network context characteristics can then even be included in quantitative analysis. In fact, such a design implies that in addition to the patient, the health service provider network forms a separate unit of analysis. The practical feasibility of such a design is limited as it requires recruiting a sufficiently large number of health service provider networks which commit to a controlled experiment. Often research designs have therefore limited the number of contexts, and/or have chosen an observational design rather than an experimental design. Indeed, empirical research in this area mostly depends on case, observational and comparative studies [17, 18]. These studies however struggle with the strength of the internal and external validity as well, thus limiting the contribution to developing the evidence base of health service operations in provider networks, as urgently called for to find effective and scalable solutions for the global problems of chronic diseases.

The contribution of this paper is to propose models and methodology to advance the development of an evidence base for health service operations in provider networks, and to overcome some of the difficulties outlined above. We propose a generic framework to derive models for health service network operations, as advocated by Berwick. The resulting models capture the characteristics of processes and outcomes as called for by the Medical Research Council [5], as well as contextual characteristics of the provider networks. Thus, they may serve to improve the internal and external validity of empirical work, facilitate accumulation of research findings, and thereby to develop an evidence base for improving health service operations in provider networks.

Before continuing, let it be recognized that outcomes are not solely dependent on structures and processes as they form part of the health service provider networks. As is well known (See. e.g. Van Aken [16]) social and political factors arising in the environment of the network, such as national or regional health policies and economic and cultural developments, may play an important role as well. In the proposed analysis methodology we therefore explicitly address assessment and interpretation of contextual factors not included in the models, thereby also shedding light on the importance of contextual factors which are included. We thus contribute to determining the extent to which outcomes can be attributed to processes and structures, as for instance called for by Rousseau et al. [13].

More precisely, our contribution is as follows:

1) Development of a conceptual framework for modelling structures, processes and outcomes of health services in provider networks
2) Development of corresponding analysis methods which enable to generate evidence regarding the relationship between health service operations and outcomes.
3) Illustration of the models, data collection, and analysis methods using a study guided by the proposed framework and methods.

The objectives of this study have been operationalized in the EU FP7 project Managed Outcomes project [19]. As recruiting and analysing a large sample of provider networks was not feasible within the time and budget constraints, the Managed Outcomes project adopted a research design in which six regional health service provider networks form the cases of a multiple case study in which provider networks form the primary unit of analysis [20]. The modelling and analysis methodology were applied to provider networks of four different conditions: Type 2 Diabetes, Stroke, Dementia, and Hip–Osteoarthritis. The first of these conditions, Type 2 Diabetes serves as an illustrative example for this paper.

The outline of this research is as follows. Section Method presents the conceptual framework, which is applied and illustrated in Illustration of specification and instantiation. Section Illustration of analysis presents and applies analysis methods. Finally Section Discussion & Conclusion discusses the framework, models and methods and considers further research directions.

Method

Conceptual framework

As the research interest is to advance the general understanding of the relationship between health service provider networks operations and outcomes, we propose a framework to develop generally applicable, replicable, and extensible models. We note however that the aforementioned 'local details' of structures and outcomes may play an essential role in their relationships with outcomes. Oftentimes such details are disease or region specific. In order to combine the general applicability desired to derive results which have validity beyond a case study or single disease with the details required to describe the relationships between health service operations and outcomes, the proposed framework identifies two *model types* and applies them at two *instance types*. The instance types are the network instance type, and the health service user instance type, thus explicitly identifying the two units of analysis discussed in the introduction. We now clarify the model and instance levels and address how they are related.

1) The basis of the modelling framework is formed by the *Generic Model*, which captures generic features of health service provider networks. It is based on Donabedian's SPO Model. The generic model is defined by means of generic *entities* which have generic *dimensions*. The entities and dimensions will be extensively discussed in the next section.

2) From the basis of the Generic model, the framework enables to derive *Disease Specific Models*, which capture the characteristics of regional service provider networks for a specific disease. A disease specific model is derived from the generic model. To this purpose, disease specific models may refine generic model components and include additional entities and dimensions.

Disease specific models still serve as an abstract specification of the entities which need to be defined to describe the operations of a disease specific regional provider network. The actual descriptions of such networks using these models are referred to as instances.

1) A *region instance* for a disease specific model is defined by the data values for the disease specific model for a specific region. A region instance includes data regarding health service users:

2) *Health service user instances* capture the relevant data values for individual health service users within a region instance.

The Generic Model and the process of Specification

The modelling framework in this research builds around a population of health service users who visit the same network of health service provider organisations. Although not strictly required, it typically applies to a region, and the network of regional health service providers servicing the regional population. For the purpose of health service operations modelling, the population does not have to be defined by the complete set of inhabitants of a region, but can be defined as a subset of this complete set of inhabitants, e.g. the subset of people suffering from Type 2 Diabetes.

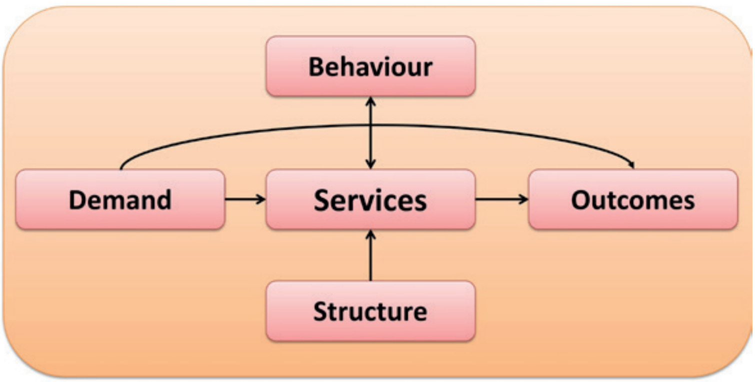

Figure 3-1 Generic model of operations and analysis

The main conceptual model as depicted in Figure 3-1 contains five entities, thereby extending Donabedian's three entity Structure-Process-Outcome model [9]. The basic entities of the generic model are: *demand, behaviour, structure, services, and outcomes*. Obviously, understanding the impact of operations on *outcomes* is the prime interest of the proposed framework and methodology. The operations are described in terms of *services* (processes) and the underlying *structures*. The entities *demand* and *behaviour* more explicitly capture the conditions of the health service users seeking health services and their health (service) behaviours:

- The entity *outcomes* refers to the results obtained through the service provisioning, referred to as health outcomes and service outcomes.
- The entity *services* replaces Donabedian's entity Processes, thus recognising contemporary understanding of the nature of the interaction with provider organisations and health service users.
- The entity *structure* refers to the resources and other static features of the regional health service provider network operations. The structure defines the available tangibles and intangibles necessary to provide the services.
- The entity *demand* forms an extension of Donabedian's original SPO model and represents the demand for health services as resulting from the health conditions of individuals in the population. As will also become clear through the illustrations, demand may by definition form an independent determinant of outcomes, and is therefore valuable in understanding outcomes and their relationships with operations.

A second extension is the explicit inclusion of the entity *behaviour*. The model takes into consideration that on the one hand the health services may influence the patients' behaviour, e.g. by inducing them to increase exercising, and that on the other hand the patients' behaviour may affect the service provisioning. For instance lack of therapy compliance may require extra services provisioning. By relating behaviour to the services, the model captures the common understanding that (health) service users are active co-creators of (health) services, rather than receivers [21]. Correspondingly, the relation between behaviour and services is thought to be bidirectional [3].

Table 3-1 describes the break-down of the 5 generic model entities, to be referred to as the level 1 components of the generic model, into further refined level 2 components.

We now briefly discuss the level 2 components in Table 3-1. *Demand* describes health service users, e.g. in terms of demographics and health conditions as furthered detailed out and illustrated below. The geography of demand can be described through demand locations; health service users can reside at health service locations. The health service users can be grouped on the basis of their health conditions into segments, for which different health services are provided. The atomic units by which *services* are defined are referred to as service elements (e.g. an outpatient visit). The next larger unit is the service journey, which is an ordered set of service elements describing the health service elements commonly used by a segment of health service users (e.g. according to an evidence based guideline). As, over time, service users may follow different transitions between the demand segments, they follow different sequences of service journeys. Such a health service user's specific sequence of service journeys is referred to as a service user journey.

Table 3-1 Components of the generic model

Abstraction Level 1	**Level 2**	**Description**
Demand	Health Service User	Service user refers to the individual patient who demands health services. Service user is defined with regard to demographic characteristics, disease history, and disease—specific medical conditions requiring the health services.
	Demand Segment	Segments refer to mutually exclusive subsets of the population of health service users with a common demand for health services (e.g. because of sharing a same health condition).
	Demand Location	Locations define areas within the geographical areas which are meaningful to distinguish because of differences in demand and or geographical properties
Services	Service element	A service element is the atomic unit of service. For each service element the resource requirements specify the type of resources (see below) required to perform the service element, as well as the expected usage of each of these types (e.g. in hours). A service element can be described in terms of an operational performance (waiting times, frequency, length of stay, transitions to another service element) and a financial performance i.e., cost. The costs of a service element are defined as the sum of the costs of the required resource usages (see below).
	Service journey	A service journey consists of a partially ordered set of service elements, which are provided to health service users from a demand segment. Operational and financial performances of a service journey are aggregated from corresponding service elements performance. The costs of a service journey are defined as the sum of the costs of the service elements involved. Transition probability refers to the distribution of health service users from the demand segment corresponding to the service journey over possible succeeding demand segments (and corresponding service journeys).
	Service user journey	User journey refers to the sequence of services that a health service user follows (defined through the sequence of service journeys). The costs of a service user journey consist of the sum of the costs of the service journeys involved.
Structure	Resource	A resource is a means to provide a service. Resources are described according to their type, availability, capacity and unit cost. With regard to type, resources are distinguished into devices, facilities, and human resources. Resource availability refers to the amount of resources which is available to deliver services per time period. Resource capacity refers to the amount of health service users that can be treated in a time period. Resource cost refers to the monetary cost of a resource per unit (e.g. per hour).

Table 3-1 Components of the generic model (continued)

Abstraction Level 1	Level 2	Description
	Service Provision Point	Provision point refers to a location where resources required to provide a service are located. Access to provision point is measured by physical distance of and travel time from the demand location of the health service user to the provision point.
	Service provider	A health service provider is a person or a legal entity who/which delivers health services to patients.
Behaviour	General health related behaviour	General health behaviour refers to the life style of the health service user, such as smoking, diet, and physical exercise behaviour
	Service related behaviour	Service related behaviour refers to behaviour which directly relates to the health services, e.g. treatment adherence or follow-up to advices by service provider.
Outcome	Health outcomes	Health outcomes are features of the health care user's health. A variety of quite different health outcomes can be considered ranging from perceived health related quality of life as reported by the health service user to specific clinical outcomes as reported by the health care provider.
	Service outcomes	Service outcomes regards both provider measures on service performance (such as waiting times) as well as health service users perceptions of service provisioning, and the valuation of the service provisioning by health service users.

The *structures* underlying the service provisioning are partly defined in terms of current and non-current assets, such as buildings and equipment (e.g. X-ray Machine 1). Each of these resources has a type (X-ray machine) and an availability (weekdays 09.00 till 16.00), a capacity (e.g. 3 patients per hour) and a cost (e.g. €100 per hour). The resources are owned by service providers, and are located at service provision points. Service providers may own resources at various service provision points, and service provision points may hold resources from various service providers. Human resources also form part of the structure. Like the tangible resources they may have a type (e.g. general practitioner), availability (32 hours per week), capacity and cost.

The generic models encompass two types of *outcomes*, health outcomes and service outcomes. Some of these outcomes such as service user perceived quality of life apply generically and can be captured in the generic model. Other health outcomes refer to disease specific measures and are included in the disease specific model. Service outcomes refer to measurements and perceptions of the services provisioning by health service users, e.g. a service user perceived timeliness, or health service user satisfaction.

Behaviour encompasses two kinds of behaviour, such as life style or diet, and on the other hand behaviour which directly relates to the health services, such as information providing or therapy adherence [7].

As already becomes apparent from the brief examples, many of the model entities needed to describe actual regional health service provider networks are not generic, but disease specific. The illustration of the model makes clear how applying the framework for a specific disease requires specification, the derivation of a disease specific model from the generic model. Illustration also requires the description of actual region and health service users: instances, briefly introduced and discussed in the next subsection.

In Table 3-2 we see that there are two demand locations, labelled 'urban' and 'rural', each comprising a number of communities. For each community some basic demographic characteristics are provided such as population size.

Model Instance and Instantiation

The process of providing the data values for a disease specific model is called *instantiation*. Hence we distinguish two types of instantiation:

1. *Health Service User Instantiation* which refers to defining the values for a health service user as defined as a level 2 component of the disease specific model. In addition to demand data, for health service users, instantiation also defines behaviour and outcome data.
2. *Region Instantiation* which refers to defining all values for level 2 components of a disease specific model defined at the regional level, in particular the data to describe the services and structures.

Table 3-2 Illustration of demand locations and population data*

Demand location	Location No.	Community	Inhabitants (2008)	Area (sq. km)	Population density
Urban area	1	Delft	96,168	24.1	3,993.7
	2	Schiedam	74,947	19.9	3,768.1
	3	Vlaardingen	70,860	26.7	2,651.9
	4	Maassluis	31,394	10.1	3,105.2
		Total	273,369	80.8	3,379.725
Rural area	5	Westland	99,299	90.6	1,096.1
	6	Midden Delfland	17,451	49.4	353.4
	7	Oostland	43,762	38.6	1,133.7
	8	Hoek van Holland	9,228	14.1	654.5
		Total	169,740	192.7	809.425
Region			443,109	273.5	2,094.575

* Source: Netherlands Organisation for Applied Scientific Research

Instantiation is also illustrated in next section. From a data collection viewpoint, the data collection for the health service user instantiation may for instance be retrieved using a survey among health service users. These service user data can form the basis to deduce region instance data, for instance to deduce values for demand segments or outcomes at an aggregated level, such as means and variances. Other data for the region instantiation may typically be collected directly through information systems or personal communication from the corresponding health service providers.

Illustration of specification and instantiation

We illustrate specification and instantiation using Type 2 Diabetes networks below. The illustration addresses specification and instantiation simultaneously, thus skipping the somewhat abstract presentation of a disease specific model without data values. The data values are mostly retrieved from the region Nieuwe Waterweg Noord and Delft Westland Oostland, as studied in Managed Outcomes. The illustrations are not meant to present complete models and instances (which are presented in subsequent publications).

Demand

The demand segments within the Disease Specific Model for diabetes are defined according to common standards concerning diabetes care. This yields the five different segments depicted in Table 3-3.

Table 3-3 Illustration of demand segments

Number	Name	Description
DS1	Prevention	Population that is at risk for developing diabetes type II
DS2	Diabetes care stage 1	Patients with diabetes type II needing lifestyle advice.
DS3	Diabetes care stage 2	Patients with diabetes type II needing lifestyle advice and oral medication.
DS4	Diabetes care stage 3	Patients with diabetes type II needing lifestyle advice, oral medication and insulin injections.
DS5	Diabetes care stage 4	Patients with complicated diabetes type II needing specialized care.

Table 3-4 illustrates generic demand dimensions and values for the region instance for the regions Nieuwe Waterweg Noord (NWN) and Delft Westland Oostland (DWO). These regions lie to the North-West of Rotterdam and covers 273 square kilometers (5.9 % of the total area in the Netherlands).

Table 3-4 provides further illustration of the regional instance, including demand volumes, or prevalence, for demand segments DS2, DS3, and DS4. These demand volumes can be defined in a variety of ways, e.g. in absolute numbers, as a function of the population (e.g. 2% of the population), or implicitly through the service definitions: service users move from one demand segment to a next through the definition of the service journeys (as described in detail below). In the example, segments are defined per demand location, while locations are either rural or urban. The presented data aggregate the rural and urban demand volumes. Such contextual information can be taken into account in the analysis (illustrated below).

Services

The generic model defines service elements to be the atomic units of the service operations. Table 3-5 provides disease specific service elements as defined by scientists and practitioners for the Type 2 Diabetes model in Managed Outcomes, but does not provide further details on dimensions of the service elements such as waiting times, service duration, unit costs, et cetera. (Cost will be discussed when illustrating the resources of the structure.)

The service provisioning is subsequently defined by defining *service journeys* per demand segment. Service journeys consist of partially ordered sets of service elements. Table 3-6 provides an illustration. As different regions may define different service journeys, these service journeys are instantiated regionally. (In fact different service journeys may also exist within a region between different locations, but we will not illustrate it here.)

Table 3-4 Illustration of demand for a regional instance

Demand characteristics	**Urban**		**Rural**		**Region**	
	N	Mean (SD)*	N	Mean (SD)	N	Mean (SD)
Age	204	65.5(10.6)	187	67.0(10.6)	391	66.3 (10.6)
Time since diagnosis	172	9.2 (7.5)	167	8.8 (7.3)	339	9 (7.4)
	N	%	N	%	N	%
Gender						
Female	88	44	79	44	167	44
Male	112	56	102	56	214	56
Total	200	100	181	100	381	100
Education						
Minimum school leaving age	49	25	50	28	99	26
More than minimum school leaving age	146	75	131	72	277	74
Demand segment (all patients in regions)						
Life style	2020	24	663	17	2683	22
Oral medication	5395	64	2689	70	8084	66
Insulin injection	963	11	488	13	1451	12
Demand segment (survey participants)						
Life style	41	22	35	20	76	21
Oral medication	121	66	110	61	231	64
Insulin injection	22	12	34	19	56	15
Total	184	100	179	100	363	100
Mother diabetes						
No	90	58	96	63	186	60
Yes	66	42	57	37	123	59
Total	156	100	153	100	309	448
Father diabetes						
No	107	76	100	74	207	75
Yes	34	24	35	26	69	25
Total	141	100	135	100	276	100

* Standard deviation

A health service user who completes the service journey of one segment may subsequently move to another segment and receive follow up services as specified in the corresponding service journey. For example after receiving prevention and screening oriented services defined in the service journey corresponding to DS1, a user may continue to the life style advice service journey of DS2. If these services are successful the health service user may continue to be in DS2 for a number of years ad repeat the service journey. More generally, each service user receives a sequence of services journeys, referred to as the *service user journey*. Figure 3-2 presents a Markov model based definition of the possible disease specific service user journeys. Every health service user instance contains the health service journey of the user. Although in practice the specification of the follow up services can be region specific, and so can therefore be the service journey definitions, the logic of the follow up service provided in Table 3-6 holds universally, and in this case these definitions can therefore be included in the disease specific model.

Table 3-5 Illustration of service elements

Element number	Service Element	Element number	Service Element
SE1	Screening-visit	SE11	Self–test glucose monitoring
SE2	Lab test outside lab	SE12	Oral medication
SE3	Lab-test-sampling	SE13	Insulin medication
SE4	Lab-test-analysis	SE14	Education
SE5	First visit	SE15	Consultation of care
SE6	Visit for diagnosis and care plan	SE16	Life style program
SE7	Follow–up visit	SE17	Insulin injection by professional
SE8	Diet consultation	SE18	Delivering medication by professional
SE9	Eye care	SE19	Prescription medicine
SE10	Foot care	SE20	Education for using insulin

Table 3-6 Illustration of the service journey per demand segment

Service Journey	Service no.	Sequence of Service Elements	Transition probability to follow up service journey
Screening	S1	SE1 --> SE3 --> SE4	S1 (NA), S2 (NA), S3 (NA)
Diagnosis	S2	SE5 --> SE2/(SE3 --> SE4)-->SE6	S3 (0.802), S4(0.139), S5 (0.012), S6 (0.020), exit (0.027)
Diabetes treatment with life style advice	S3	SE3 --> SE4 , SE6, SE8, SE9, SE10, SE14, SE16 (with no predefined precedence)	S3(0.802), S4(0.139), S5 (0.012), S6 (0.020), exit (0.027)
Diabetes treated with life style advice and oral medication	S4	SE3 --> SE4 , SE7, SE8, SE9, SE10, SE12, SE14, SE16, SE18, SE19 (with no predefined precedence)	S4 (0.868), S5 (0.026), S6 (0.015), exit (0.091)
Diabetes treated with life style advice and/or oral medication and insulin therapy	S5	SE3, SE4, SE20, SE7, SE8, SE9, SE10, SE11, SE12, SE13, SE15, SE17, SE19 (with no predefined precedence)	S5(0.692), S6 (0.057), exit (0.251)
Diabetes treated with life style advice and/or oral medication and insulin therapy	S6	SE3, SE4, SE20, SE7, SE8, SE9, SE10, SE11, SE12, SE13, SE15, SE17, SE19 (with no predefined precedence)	
Specialized diabetes care		Not studied in this research.	

The transitions from health service users from one service journey to the next are modelled by transition probabilities, as illustrated by Table 3-6. The transitions between the segments and accordingly service journeys define a Markov process. As we enforce a one-to-one correspondence between segments and services, the proposed model coincides with health state based Markov models as commonly encountered in epidemiologic models (See e.g. [22, 23]). Figure 3-2 provides a graphical representation of the Markov model corresponding to Table 3-6. In combination with incidence data it dynamically defines the prevalence of the demand segments.

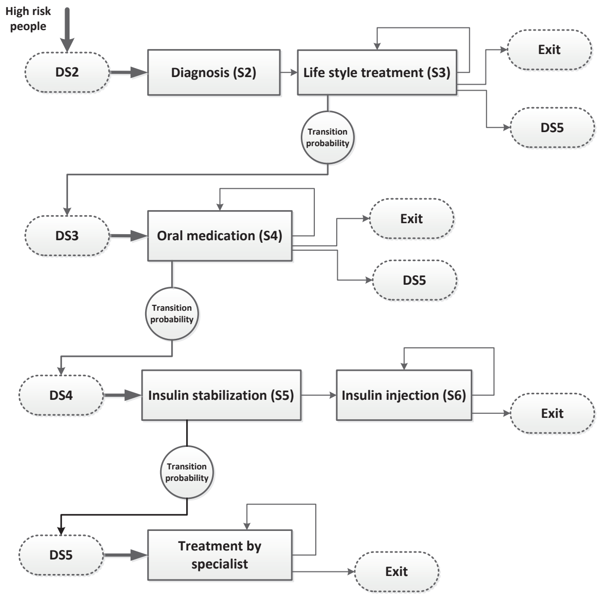

Figure 3-2 A Markov model representation of the service user journey

Structure

The structure of the regional health service provider network is illustrated using the level 2 components. The entity Service Provider is a main structure component, which represents the health service provider organizations involved. Service Provision Points (SPPs) specify the locations where the service providers reside. A service provider can operate in several locations, and conversely one location may host more than one service provider. Providers have resources in the SPPs in which they operate.

The resources identified in the Managed Outcomes project are defined in terms of the *resource types*, the *capacity* per type, and the *cost* per capacity unit. Three basic classes of resources are human resources, facilities, and devices. Cost will typically be defined in cost per time unit, but other cost drivers (such as per m^2, per use, are equally feasible). Table 3-7 identifies resources required to perform the service elements in the Dutch regions used as an illustration. The diabetes health service provider network in the region NWN & DWO consists of practices of G.P.'s which are abstractly summarized in Table 3-7.

Table 3-7 Illustration of Service provision points (SPPs) in relation to service providers

Health Service Provider	SPP name	SPP description	Available resources	Location *
GPs	SPP_{1-103}	Single GP practice, health centre, etc.	GPs, lab technician, practice nurse, diabetic nurse	1, 2 ,3, 4, 5, 6, 7, 8
Lab	$SPP_{104-130}$	Lab	Lab technician	1, 2 ,3, 4, 5, 6, 7, 8
Dietician	SPP…	Dietician	Dietician	
Optometrist	SPP…	Optometry	Optometrist	
Podotherapy	SPP…	Podotherapy	Podotherapist	
Physiotherapy	SPP…	Physiotherapy	Physiotherapist	
Life style consultation	SPP…	Life style consultant	Life style consultant	
Pharmacy	SPP…	Pharmacy	Pharmacist	
	SPP…	District nursing care	District nurse	
Hospital	SPP…	Internal medicine office	Internal medicine specialist	1

*Demand locations are described in Table 3-2 .

A first relationship between structures and services is established by defining the resource use per service element as presented in Table 3-8. The reader may notice that demand is defined by means of segments, for which the service journeys are defined as well as the volumes per location. Combining this with the relationship between service elements and resources (use), the model thus makes it possible to translate demand and the progression of demand using incidences and transition probabilities to resource capacities requirements for the locations of a region instance.

The generic model defines costs at the resource level, and facilitates specification of various cost drivers in the disease specific models. Noticing that the resource use of the service elements is modelled, as depicted in Table 3-8, the costs of service elements can be calculated using activity based costing[24], which enables time driven activity based costing as advocated by Kaplan & Porter [25]. These costs may vary per location. Subsequently, one may calculate location dependent costs for service journeys, and indeed via the demand volumes and transition probabilities, expected costs of demand segments according to the health service user journeys.

Inclusion of material costs per service element is straightforward. The material costs can be assigned directly to the service element in which they are used according to the service element definition. For Type 2 Diabetes, for example, using the medicine ‘insulin’ is a material corresponding to the self-service element ‘inject insulin twice daily’. Including materials and/or medicine requires adding the relevant materials to the definition of the service element. Information of total cost per service element in NWN & DWO is given in Table 3-8.

Behaviour

As is the case for services in general, health services are co-created by service user and providers [26]. This co-creating behaviour is therefore included in the model, next to non-service related health behaviour. The distinction may not be easy to make, and the model does not require a strict distinction.

Table 3-8 Illustration of resource requirements and costs of the service elements

Element number	Service Element	Resources	Resource description	Resource requirements	Costs
SE1	Screening-visit	GP	General Practitioner	20 minutes	50.0
SE2	Lab test outside lab	Doctor assistant	Assistant (not a nurse) of physician	5 minutes	2.9
SE3	Lab-test-sampling	Lab	Laboratory technician specialized in blood sample taking and tests.	5 minutes	3.8
SE4	Lab-test-analysis	Lab		1 minute	0.8
SE5	First visit	GP		20 minutes	50.0
SE6	Visit for diagnosis and care plan	GP		20 minutes	50.0
SE7	Follow–up visit	Practice nurse	Nurse that assists a physician by taking over routine care	20 minutes	21.7
SE8	Diet consultation	Dietician	Dietician	45 minutes	48.8
SE9	Eye care	Optometrist	Professional in eye care (not an ophthalmologist)	5 minutes	5.4
SE10	Foot care	Practice nurse		5 minutes	5.4
SE11	Self–test glucose monitoring	Test Kit	Kit that contains material for testing glucose level	1 kit	2.0
SE12	Oral medication	Medicine	Oral medication	1 pill	1.0
SE13	Insulin medication	Insulin	Insulin medication	1 dose	5.0
SE14	Education	Diabetic nurse	Nurse specialized in care for Diabetic Patients	20 minutes	21.7
SE15	Consultation of care	Specialist	Specialized Physician (not a GP)	10 minutes	30.0
SE16	Life style program	Life style consultant	Professional specialized in life style advice	20 minutes	21.7
SE17	Insulin injection by professional	District nurse	Nurse that provides care at patient's home	20 minutes	21.7
		Insulin		1 dose	5.0
SE18	Delivering medication by professional	District nurse		20 minutes	21.7
SE19	Prescription medicine	Pharmacist	Professional delivering medication	1 time	10.0
SE20	Education for using insulin	Diabetic nurse		20 minutes	21.7

Non-service related health behaviour intends to model life-style attributes such as smoking, alcohol consumption, diet and physical exercise. For each health service user, this health related behaviour data complements the static (health condition) data described under demand. The service co-creation may regard information exchange with the health service providers, therapy adherence, no-show, et cetera. For the Type 2

Diabetes specific disease model the choice of behaviours modelled in Managed Outcomes is depicted in Table 3-9.

Naturally, behaviour is instantiated primarily at the health service user level. Instantiation at the health service user level will also turn out to be useful to explore relationships between behaviour and outcomes as illustrated in the next Section. Table 3-9 illustrates behaviour data from the region instances as composed by aggregating health service user instance behaviour data. These data can be collected using questionnaires and/or from electronic health records.

Outcomes

Relevant outcomes are often specified in the disease specific model, as the outcomes measures themselves are often disease specific. An example is the commonly accepted clinical outcome measure of HbA1c-level for Type 2 Diabetes health service users. Other health outcomes however can be general, e.g. mortality or quality of life.

Table 3-9 Illustration of behaviour

General health behaviours	Urban	Rural	Service-related behaviours	Urban	Rural
Smoker	9%	11%	Adherence to life style advices *	3.32	3.74
Drinker of alcoholic beverages	63%	71%	Adherence to oral medication *	4.82	4.82
Exercise (mean days per month)	7.04	7.37	Adherence to injection *	3.92	4.49

* 1=Worst value, 5=best value.

Perceptions of health outcomes and health services refer to mental representations of features of actually existing health outcomes and health services. To collect perceptions, it is required to approach health service users and ask for their perceptions. A common instrument to collect perceptions of health services is the SERVQUAL questionnaire, of which health service specific versions are for instance proposed by Bowers et al. [27]. These perceptions regard the quality dimensions empathy, reliability, responsiveness, caring and communication. Using these data collected at the health service user instance level, one may generate aggregated regional measures such as means and variances, for perceptions of demand segments or populations. For some measures, such as (perceived) waiting times, it may be insightful to collect data both using questionnaires as well as through provider information systems (See Table 3-10).

Evaluations of health outcomes and health services are judgments based on the corresponding perceptions and with reference to internal values. The generic model includes general health related quality of life as measured with the EQ-5D. This encompasses a self-rating with regard to five dimensions of health (mobility, ability of performing self-care, ability of performing usual activities, pain/discomfort, anxiety/depression) and a rating of the present health state using a visual analogue scale which is anchored with 0 for the worst imaginable health state and 100 for the best imaginable health state [28]. Moreover, the methodology for evaluating the EQ-5D also provides scoring functions by means of which the patterns of ratings for the five dimensions can be mapped onto a utility index which is anchored with 0 for death and 1 for full health. The function which is mostly used for this purpose is that of Dolan [29].

To illustrate the outcome measurement, Table 3-10 displays for the Type 2 Diabetes disease specific model the outcome measures HbA_1c, blood pressure, and LDL cholesterol, and the mean values for the region Nieuwe Waterweg Noord, all of which are obtained through the service providers. The other outcome measures in Table 3-10 are averages of health service user perceptions, as measured through questionnaires. The SEVQUAL-5 value summarizes the scores for the five aforementioned dimensions [30] by summing them and rescaling to the range 0 (minimum) - 100 (maximum). The illustration of analysis in the next section uses more detailed SERVQUAL data.

Table 3-10 Illustration of outcome measures and perceptions

Health outcomes	Average/ Mean	Service outcomes	Average/ Mean
HbA1c<7	72.4 %	Waiting time in a SPP (minutes)	13.24
Blood pressure<140	4.5 %	Right communication with provider	90 %
Cholesterol<4.5	44.4 %	SERVQUAL (Summed 5 values)	87 %
LDL<2.5	44.7 %	Evaluation of service quality in comparison with best imaginable service	86 %
Patients had stroke	3.6%	Services satisfaction	86 %
Patients having kidney failure	0.0%		
Patients having problems with heart	30.2%		
Patients having problems with lower extremities	11.8%		
Patients having problems with sight	21.8%		
EQ-5D utility index *	0.77		
EQ-5D visual analogue scale	69.1 %		
Satisfaction with health	51.9 %		

* The scale is standardized with 0 for death and 1 or full health.

Analysis Methods

The models and instances illustrated in the previous section enable to describe health service network operations for disease specific purposes both for regional health service provider networks and for the health service users. The resulting descriptions are insightful in themselves as they clarify the often only implicitly known operations within a network in relation to demand, behaviour and outcomes. Moreover, these descriptions can be compared between regions. The main purpose of the model is however not to provide descriptions as such, but to advance scientific understanding of the relationships between operations and outcomes, as argued to be of importance in the introduction.

For this purpose the models can be applied using various research designs. As mentioned in the introduction, one possible design is to consider an intervention study. A simple intervention study is to implement a single managerial intervention in a single network and conduct a before-after study including multiple health service users. Even if the included population of health service users is large and the experiment is randomized and controlled, the results are only valid for the operations within the specific network, and hence have limited value for a more general understanding of the relation between operations and outcomes. This can be remedied by considering an intervention study in multiple networks. Such studies however are typically difficult to set up and may experience problems regarding controlled implementation. An often feasible alternative approach is to conduct an observational multiple case study, as is applied in the Managed Outcomes project from which the illustrated models and instances are taken. (The Managed Outcomes project includes 6 regions in 6 different countries, and 4 diseases.) Multiple case observational studies are quite feasible to set up, and can be readily complemented by future researches. We therefore view them as an appropriate design to advance evidence based operations management in health service provider networks, and present analysis methods based on this research design below. In fact, the research design presented below relies on a basic cross sectional approach in which there is no longitudinal element. From a methodological viewpoint, this approach implies that causal relationships between changes in operations and changes in outcomes cannot be inferred. A further discussion of longitudinal approaches is presented in the discussion section.

Following our main conceptual model we investigate the relationships between structures and processes and outcomes, while taking into account the relationships with demand and behaviour. To do so, we often control the analysis of relationships between outcomes on the one hand and structures and processes on the other hand for demand and behaviour.

As we have argued in the introduction, context plays a role in the relationship between operations and outcomes. In so far as the context is part of the operations, in particular is part of the structure of the regional provider network, it is modelled and can be analysed as such. Still, one should not expect to explain (differences) in outcomes in relation to (differences in) operations as the relevant context may certainly also lie beyond the scope of the operations, e.g. in the regional characteristics, the health system, societal trends, et cetera. These contextual factors are not included in the model and can therefore be not explicitly analysed. The analysis can nevertheless shed light on the relevance of contextual factors, as will be demonstrated in the analysis below.

Before demonstrating the analysis framework, let us recall that operations are instantiated in the regional instances, and therefore the relationship between outcomes and operations are analysed for regional health service provider networks, not for health service users. The networks are the main unit of analysis; information about the health service users is used to support this analysis.

Analysis approach

We now first address how to control for differences in health service demand and general health behaviour, given a collection of region specific instances. In principle it is possible to define the demand segments in such a way that the health service users in a segment agree on all values for the dimensions of the health service user instances, i.e. on demographic characteristics, general health behaviours, and co-creation behaviour (for instance same age group, gender, smoking behaviour, therapy adherence, et cetera) [31]. If this is the case, all variation in the demand and behaviour between the health service users of different networks is eliminated, and hence it cannot act as confounding factor when exploring the relationship between operations and outcomes. This may however be practically infeasible and/or or lead to very small demand segments. Hence we take into account that variation exists between health service users in a demand segment, e.g. some smoke and others do not. Such variation can produce differences in outcomes. It is often possible to control for such differences by specifying a multivariate regression model in which dimensions of health service demand and general health behaviour act as independent variables and the dimensions of outcomes as dependent variables. The thus found relationships describe how variations in demand and behaviour among health service users from all regions influence outcomes per segment. In this way, the influence of demand and behaviours can be controlled for in the exploration of relationships between operations and outcomes.

The variation in outcomes not explained by the control variables is a candidate to be attributed to operations [32]. We now proceed by outlining methods to identify relationships between operations and outcomes. The basic approach relies on the instance descriptions, both taking the qualitative descriptions of structure, services and co-creating behaviours into account, as well as the quantitative data collected.

The approach operates bi-directionally in its exploration of relationships between operations and outcomes. It explores relevant differences in outcomes and seeks for corresponding differences in operations, and vice versa. As there are many more different (combinations) of outcome dimensions and operations dimensions to consider, statistical analysis is likely to yield unstable and unreliable results when analysing all possible relations. We therefore propose the search for evidence to be guided by state of the art scientific understanding. This may be operationalized by assigning an expert panel to identify relevant outcomes, operations, and combinations thereof (using for instance a Delphi method) [33]. Alternatively, researchers may select relevant outcomes, operations and combinations of both for analysis based on current scientific understanding and interests. Below we refer to the people who perform these analyses as *the analysts*.

1. The analysts consider all (controlled) outcomes and identify notable differences among the various region specific instances. Subsequently, hypotheses are formed regarding the operational causes of the differences in outcomes using a) the scientific evidence base and b) the analysts' assessments.
2. The analysts consider all region specific instances and identify notable differences in resources, services, co-creation behaviour, and health service user perceptions of the operations. Subsequently, hypotheses are formed regarding outcome effects resulting from these differences in operations using a) the scientific evidence base and b) the analysts' assessments.

In many cases, the selection of notable different outcomes by the analysts can be guided by statistical testing for significance of difference. The relatively modest number of cases can limit the strength of statistical approaches, in which case other methods can be used as illustrated in the next section.

Illustration of analysis

Rather than presenting a full analysis for the Type 2 Diabetes model, only the principles of the analysis of the relationships between operations and outcomes are illustrated. We focus on the analysis for health service users in demand segment 4 (DS4), who inject insulin. Additional data for analyses is presented online at the Researchgate.

Step 1: Difference in outcomes

We first discuss selecting notably different outcomes. To this purpose the analysts can systematically consider all outcomes measured in the disease specific models at the regional level, taking averages and variances over health service user outcome measures when applicable, and relying on statistical significance of differences when possible. Moreover we suggest to primarily focus on (intermediary) outcome measures such as HbA1c level or satisfaction with health services, which are more likely to be related directly to operations, rather than on functional outcomes such as quality of life whose relationship with operations is via the intermediary outcome measures [34]. For illustration purposes however we also include functional outcome measures such as quality of life.

Table 3-11 presents outcome data from the six region specific instances in Managed Outcomes for health service users in DS4. To illustrate the process of considering differences in (controlled) outcomes and finding related operations, we consider both service outcomes and health outcomes, and we consider outcomes at the health service user level as well as at the regional level. We control for differences in demand and behaviour when possible. Likewise we control for regions as a contextual construct in the analysis when possible. Doing so, is a first step in the process of distinguishing the relationship between the modelled operations and outcomes from non-operational context such as demand characteristics.

Table 3-11 Illustration of health outcomes

Case	Keski-Suomi	Bamberg	Herakleion	NWN &DWO	Valencia	Tower Hamlets	Total
Proportion (%) of patients with HbA_1c < 53 mmol/mol	77		42	72	60	56	
EQ-5D utility score [a]							
N	54	85	41	54	24	93	351
Mean	0.77	0.72	0.66	0.80	0.63	0.56	0.68
SD	0.19	0.20	0.19	0.17	0.24	0.25	0.23
Service satisfaction [b]							
N	53	82	43	53	26	92	349
Mean	90.3	80.1	74.4	84.3	69.9	69.0	77.9
SD	16.2	23.9	24.2	22.7	23.6	25.0	24.1

[a] The scale is standardised with 0 for death and 1or full health.

[b] The scales are scored from 0 for ‘extremely dissatisfied’ respectively to 100 ‘extremely satisfied’ respectively.

The analysts may hypothesize first notable differences among regions with regard to the proportions of health service users whose HbA1c level is effectively controlled (HbA1c<53 mmol/mol), or with regard to average satisfaction with services.

The service satisfaction data were collected via questionnaires from health service users. A one-way analysis of variance (One-way ANOVA) test reveals that differences between regions exist, $F(5,343)=7.55$, $p<.001$. As variances between regions are significantly different, the Welch test should be reported in addition to the previous test. Welch's adjusted F ratio is significant, $F(5,125.51)=9.40$, $p<.001$. It can be concluded that at least two of the six regions differ significantly on their average satisfaction scores.

The post hoc comparison, using Hochberg's GT2 (Table 3-12), shows that average user satisfaction in Tower-Hamlets is significantly lower than in Bamberg, Keski-Suomi and NWN &DWO. Moreover, average user satisfaction in Kesk-Suomi is also significantly higher than in Valencia and Herakleion.

Table 3-12 Illustration of comparison of satisfaction with services

	Networks	Mean	Mean differences ($X_i - X_j$)					
			1	2	3	4	5	6
1	Tower-Hamlets	69.0						
2	Valencia	69.9	-0.85					
3	Bamberg	80.1	-11.06*	-10.21				
4	Herakleion	74.4	-5.40	-4.55	5.66			
5	Keski-Suomi	90.3	-21.23**	-20.38**	-10.17	-15.83*		
6	NWN &DWO	84.3	-15.25**	-14.40	-4.20	-9.86	5.97	

*p<.05, **p<.01

We now further explore relationships between the service satisfaction and demand, behaviour and operations. The regression analysis which relates satisfaction to a basic set of demand and behaviour variables is presented as Step 1 in Table 3-13, and explains 10% of the variance. If one adds dummy variables for the regions to take regional context into account, the model explains an additional 5% of the variances: Keski-Keski-Suomi has significantly more satisfied health service users. In this model Tower-Hamlets is the benchmark for comparison between regions.

The analysts may subsequently hypothesize along with Bowers et al that the service quality dimensions perceived empathy, timeliness, responsiveness, caring and communication are determinants of satisfaction with services. Such hypotheses would be further supported by more recent work of Trout et al. [35] who report association of waiting time and patient-provider communication with service satisfaction or Fornell et al. [36] who more generally find that satisfaction is quality-driven. Table 3-12 illustrates that including the aforementioned perceptions of service quality dimensions in the model leads to an explained variance of 50%. Among the added variables, timeliness and responsiveness are significant, and in this third model, none of the demand and behavioural variables is significant. Of the variables representing the regional contexts, only Valencia is now significant. Moreover, this third model indicates that the higher satisfaction in Keski-Suomi found in the second model is now explained by the higher timeliness and responsiveness. The significance of Valencia's dummy variable suggests that either there are non-operational contextual factors which are significantly related to satisfaction with health services, or that operational characteristics exist which have not yet been included in the model, but are significantly related with satisfaction with health services. The latter may be revealed by step 2 of the analysis in which differences in operations are taken as a basis to formulate hypotheses about differences in outcomes. In so doing, it may be possible to increase the level of explained variance above 50% as illustrated below (thus leaving less than 50% for non-operational context). As a final remark we observe that the significantly related perceptions of operations timeliness and responsiveness are indeed classical dimensions of operations for which operations research and operations management methods for improvement exist.

Table 3-13 Satisfaction with services in the research regions [a]

Step	**Variables**	**β** **Step 1**	**Step 2**	**Step 3**
1	Age	.05	.05	-.02
	Gender	-.03	-.04	.01
	Education	.07	-.05	-.05
	Time since Diagnosis	.00	.01	-.06
	Drink	.16*	.13	.02
	Smoking	.02	.03	-.02
	Physical activity	.05	.06	.07
	HbA1Cknown	.20**	.19**	.06
	Insulin intake fulfilment	.01	-.01	-.03
2	Valencia		-.09	-.13*
	Bamberg		.08	-.10
	Herakleion		-.02	-.01
	Keski-Suomi		.22*	.05
	NWN &DWO		.14	.04
3	Tangibles			.12
	Timeliness			.17*
	Responsiveness			.20*
	Empathy			.08
	Caring			.09
	Communication			.14
	ΔR^2		.05	.35
	R^2	.10	.15	.50
	F change	2.51*	2.56*	23.20**
	df1	9	5	6
	df2	211	206	200

[a] Standardised coefficients; *p<.05; **p<.01 (two-tailed)

In the Managed Outcomes project, the HbA1c data are not collected via health service user questionnaires but have been reported as averages by the health service providers. This data is not obtained from the health service user instances, but comes directly from the regional instances through provider information systems. Therefore, variance per region is not known, nor can it be related to outcomes at the health service user level. The data can however be related to outcomes at the regional level. Considering that the research on which this illustration is built only contains 6 regions, statistical analysis is unlikely to reveal significant differences. Nevertheless, other forms of analysis are possible. For instance the proportions of health service users whose HbA1c is below the threshold value can be visualized in comparison to the hours of care received as depicted in Figure 3-3. Especially the results from Keski-Suomi and Heraklion contradict any hypothesis regarding a one dimensional relationship stating that more hours of care lead to better glycaemic control.

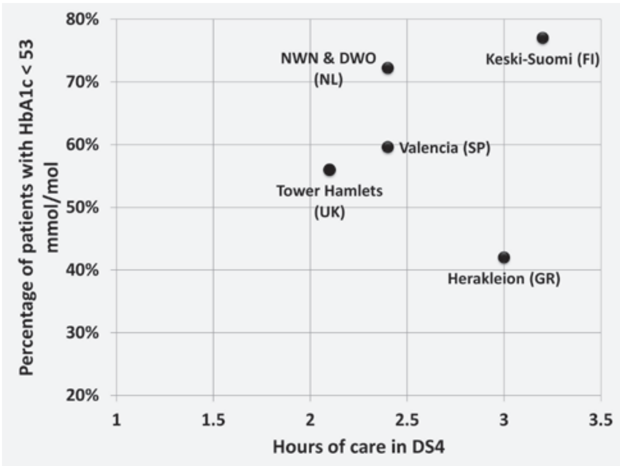

Figure 3-3 Relationships between hours of care in DS4 and effective control of HbA1c

Step 2: Differences in Operations

We now illustrate how analysts can systematically identify notable differences in operations to form hypotheses regarding related differences in outcomes. To this purpose we consider resources and services, and also consider perception of health service operations quality. Moreover we address effects on service outcomes and on health outcomes. We specifically illustrate two specific differences in service provisioning as specified in the region specific instances:

1. The comprehensiveness of follow up service
2. The human resources used for providing follow up services

Figure 3-4 graphically represents service elements and average hours of care for DS4 for 5 of the region specific instances studied in Managed Outcomes. Most hours of care in this journey are allocated to follow up service. The activities in follow up visit include prescription renewal, eye examination, examination of lower extremities, and diet and life style counselling. Comprehensiveness is defined as the degree of thorough discussion between user and provider so that all diabetes issues and related questions are discussed. Despite the small number of networks, the differences between the networks regarding the comprehensiveness are significant, $F(5, 365)=6.0$, $p<.001$, Welch F ratio $(5, 130.2)=7.09$, $p<.001$. Parchman et al. [37] reports that providing more comprehensive visits results in better outcomes. Along with findings reported by Parchman et al. we therefore hypothesize that more comprehensive follow up visits are associated with an increasing EQ-5D utility and service satisfaction.

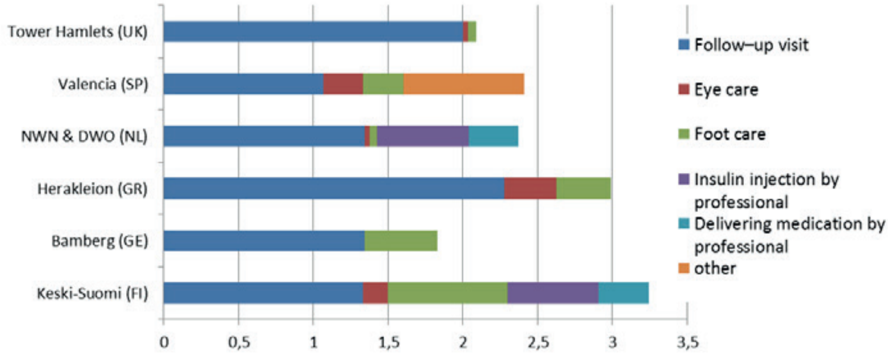

Figure 3-4 Hours of care for DS4

The first hypothesis, indicating that increased comprehensiveness of follow up visit is associated with better outcomes, is analysed using health service user instance data in addition to region instance data. The regressions analysis rejects the hypothesis that a higher degree of comprehensiveness results in higher EQ-5D scores (step 3 in Table 3-14). The model which includes comprehensiveness of care increases the explained EQ-5D variation, but the effect is not significant, nor is the change in explained variance significant. These findings differ from the aforementioned findings by Parchman et al.

The effect of the comprehensiveness of consultation on satisfaction with services on the other hand, is significant and increases explained service satisfaction variance from 14% to 26%. Table 3-15 therefore reports an additional analysis step which explores whether explaining satisfaction with services using a combination of region, timeliness, responsiveness – the three variables found to be significant in step 1 - and comprehensiveness of consultation increases the explained variance in satisfaction with services when compared with the results of Table 3-13. This additional analysis step reveals that Valencia as a contextual construct is now not significantly related to satisfaction anymore, suggesting that this negative correlation is due to incomprehensiveness of the service provisioning. In Table 3-14 only variables representing operations are significantly related to satisfaction with services.

To hypothesize effects of differences in human resource use, we refer to Collins et al. [37] and Vrijhoef et al. [38], who investigated the effects of human resource involved in providing the health services on quality of life and HbA1c in diabetes patients. In Keski-Suomi and NWN this service is provided by a collaboration of GPs and nurses; whereas, in other regions the service is provided by the GP or internist. Based on the aforementioned evidence, we hypothesize that Keski-Suomi and NWN have better EQ-5D scores.

Table 3-14 Illustration of relationships between comprehensive consultation and outcomes [a]

Step	Variables	EQ-5D score			Service satisfaction			
		β Step 1	Step 2	Step 3	β Step 1	Step 2	Step 3	Step 4
1	Age	-.10	-.15*	-.16*	.05	.05	.03	-.05
	Gender	.07	.08	.08	-.03	-.03	-.05	-.01
	Education	.23**	.12	.11	.07	-.04	-.06	-.04
	Time since Diagnosis	-.11	-.08	-.08	-.01	.01	.01	-.04
	Drink	.18**	.15*	.15*	.14*	.11	.09	.01
	Smoking	-.03	-.02	-.02	.00	.00	-.01	-.03
	Physical Activity	.03	.01	.01	.05	.06	.05	.04
	HbA1C known	.24**	.17**	.16**	.19**	.18*	.13	.03
	Insulin intake fulfilment	.17**	.11	.11	.04	.01	-.01	-.02
2	Valencia		.11	.11		-.09	-.11	-.10
	Bamberg		.23**	.22**		.10	.06	-.08
	Herakleion		.11	.10		-.01	-.06	-.04
	Keski-Suomi		.24**	.23**		.22**	.15	.05
	NWN &DWO		.30**	.29**		.15	.08	.02
3	Comprehensive consultation			.05			.36**	.21**
4	Tangibles,							
	Timeliness							.24**
	Responsiveness							.38**
	Empathy							
	Caring,							
	Communication							
	Δ R^2	.32	.06	.00		.05	.12	23
	R^2	.32	.37	.38	.10	.15	.27	50
	F Change	11.65**	3.93**	.66	2.43*	2.69*	33.67**	49.91**
	Df1	9	5	1	9	5	1	2
	df2	225	220	219	219	214	213	211

[a] Standardised coefficients; *p<.05; **p<.01 (two-tailed)

This second hypothesis is tested using multiple regression models in two steps (Table 3-15). In step one the effects of demand and behaviour are modelled. The modelling of the involvement of a nurse is done using a binary variable, which has value 1 for health service users in Keski-Suomi and NWN, and 0 for others. As this variable is therefore not independent from the regional variables commonly included in the aforementioned models to capture context, these regional variables cannot be added to the model as well. Thus the usual second analysis step is now omitted.

Table 3-15 Analysis of effects of human resource models on EQ-5D score [a]

Step	Variables	B	
		Step 1	Step 2
1	Age	-0.10	-0.10
	Gender	0.08	0.08
	Education	0.23**	0.18**
	Time since Diagnosis	-0.11	-0.09
	Drink	0.18**	0.17**
	Smoking	-0.04	-0.03
	Physical Activity	0.02	0.03
	Insulin intake fulfilment	0.18**	0.16**
	HbA1c known	0.24**	0.22**
2	Care model		0.18**
	ΔR^2		0.03
	R^2	0.32	0.35
	F Change	11.65**	9.52**
	Df2	2	1
	Df1	232	231

[a]Standardised coefficients; *p<.05; **p<.01 (two-tailed)

As shown in Table 3-15, step one explains for 32% of variations in EQ-5D score. Inclusion of the care model variable increases the explained variance of EQ-5D by 3%. This difference is significant, and the same holds true for the binary variable representing the involvement of the nurses. These modest results confirm the findings of Collins et al. and Vrijhoef et al., who report significantly higher quality of life with the GP/nurse model when compared to traditional care.

We conclude by noticing that relationships exist among outcome variables (or among operational variables), which are worthy of further exploration. A first example is to explore the often debated relationship between service satisfaction and health outcomes. Moreover, one might explore mediating roles of outcomes variables, for example exploring if the clinical outcome measure HbA1c level is a mediator from operations to quality of life as measured through EQ-5D. Likewise, operation variables may mediate effects, for instance from structures to services to service perceptions. For an example, resource capacity in proportion to demand is likely to be related to waiting times; shorter waiting times may yield lower transition probability between progressive demand segments. Although we didn't illustrate such analyses, the proposed model and analysis methods enable empirical testing of such hypothesized relationships.

Discussion & Conclusions

This paper proposes models and methods to advance scientific understanding of the relations between operations and outcomes of health service provider networks. Such networks are of increasing importance as prevalence of age and life style related chronic diseases increase. So far however, health service operations management studies have mostly been case studies at organisational or sub-organisational levels, and typically disregard outcomes. Moreover, scientific literature on implementation and evaluation is scarce. Hence, operations management has contributed little to improve the evidence base and understanding of the effectiveness of health service provider networks. Conversely, health services researches regarding age and life style related diseases haven't put much effort in systematically addressing the operations in the health service provider network. Hence the evidence developed in health services research lacks systematic approaches to health service operations. This paper proposes a generic model from which disease specific models can be derived and corresponding analysis methods to commence bridging the gap between operations management and health services research on regional provider networks. The analysis methods importantly rely on quantitative methods and explicitly address non-operational contextual factors.

Of course, the contribution of the proposed models and methods can only be assessed through application and further research. Already in the illustration presented in the previous section however, the models explain more than half of the variation of satisfaction with services for a particular demand segment through operations. For the same segment of diabetes patients who use insulin injections, the models explain more than one third of the variation in health-related quality of life (EQ-5D). Equally interesting, the illustration reveals that variation between regions in average hours of health service provisioning appears to be unrelated to the proportion of patients in the region for which the HbA1c level is below the threshold.

Using this publication as a common base reference, and thus using the models and methods proposed in this study, subsequent publications will address comparative effectiveness of health service provider network operations in six European countries for Type 2 Diabetes, Stroke, and Hip surgery. The findings of these papers and a methodological reflection on these findings will further clarify the contributions of the models and methods proposed. These publications hopefully serve as an accelerator for evidence based health service operations in networks, and serve to direct further improvement of modelling and analysis.

To this purpose we note that the reach of the proposed models stretches beyond the boundaries of the research design and analysis methods discussed in this paper. As already mentioned, the proposed models can be used in intervention studies, e.g. in a multiple case study design. Such studies are likely to provide further insights in understanding the causality of relationships between operations and outcomes, more specifically regarding the effects of interventions in operations to improve outcomes. An intermediate step towards advancing evidence on causal relationships is to follow cohorts of regional provider networks. Such studies can also advance understanding of the mechanisms which explain how context and interventions combinedly impact outcomes (in accordance with the CIMO logic).

Donabedian [9] already posited that the relationships between processes and outcomes are not direct but that an inference chain exists. We have mentioned such inferences in the previous section, e.g. from structures to services to service perceptions to intermediary outcomes and to functional outcomes. These lines of analysis are not explored in this paper, but certainly important to advance the understanding of the relationship between operations and outcomes. This also broadens the scope of the operations management perspective beyond the current straightforward service and structure entities to operations management constructs such as network coordination or quality improvement practices.

Given the current scientific understanding however, broadening of the current evidence using the models and methods outlined above may well appear more valuable than applying improved designs and analysis methods. Despite the theoretical nature of our work, the main contribution lies not in the advancement of research itself, but in providing a foundation for evidence based improvement of operations in health service provider networks for the highly prevalent chronic diseases of the 21st century.

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Chapter 4

Modelling and Evaluation of Diabetes Provider Networks in Primary Care

This chapter is based on:

Mahdavi, M., Vissers, J., Konerding, U., Elkhuizen, S., van Dijk, M., Vanhala, A., Karampli, E., Faubel, R., Forte, P., Coroian, E., van de Klundert, J., Modelling and evaluation of diabetes provider networks in primary care. This chapter is presented at 39th conference of Operations Research Applied to Health Services (ORAHS), Istanbul 2013.

The manuscript is under review for publication.

Abstract

Background: Type 2 Diabetes is a major global health concern. In this study we research the relationships between health service operations and outcomes of type 2 diabetes in primary care networks in six European countries.

Methods: The research applies the models and observational multiple case study methods proposed in our previous research for modelling and evaluation of health service provider networks. Firstly we present a type 2 diabetes specific model to describe the demand for health services, the health service network and the outcomes obtained. Using this model we describe primary care networks for type 2 diabetes by six case studies in six European countries. Case studies include descriptions of networks' operations and cross-sectional study of patient behaviour and outcomes as well as operations. Subsequently we analyse the relationships between differences in outcomes and differences in operations, primarily using regression models.

Results and discussion: The analysis focuses on three outcome measures: Glycated haemoglobin level (HbA1c); health related quality of life and satisfaction with services. For the diverse population of type 2 diabetes patients in six different European regions, the hierarchical regression model presented explains 28% of the variation in EQ-5D utility and 46% of service satisfaction, the latter almost exclusively related to service operations. Greater involvement of nurses in type 2 diabetes treatment is one of the operational improvements most positively correlated with increased quality of life. The findings confirm the relevance of some, but not all, of the earlier established service quality dimensions from the ServQual model for service satisfaction. The analysis identifies several operational characteristics of regions which obtain better outcomes, both in terms of percentage of patients with a controlled HbA1c level, and in terms of quality of life at lower health service use and lower costs.

Conclusions: The operational models, which capture service operations at the network level rather than the patient level, explain as much of the variance in quality of life by service operations as by (demographic) demand factors. Moreover they explain almost half of the service satisfaction. Given these promising results, and their universal applicability, they form a sound basis to advance the evidence base and understanding of the operations management of primary care networks for type 2 diabetes.

Key words: Type 2 diabetes, provider networks, operations management, outcomes

Background

The prevalence of diabetes has been estimated to amount to 347 million people around the world in 2008, of which around 90% have type 2 diabetes (T2D) [1]. Although T2D is preventable, it is predicted to become the seventh leading cause of death globally. The World Health Organisation prevalence estimate for Europe among adults of age 25 years or older amounts to 10.3% for men, and 9.6% for women [2]. According to the International Diabetes Federation[3], the prevalence of diabetes among adults (20 years or older) in Europe amounted to 55.4 million in 2010, yielding a prevalence of 8.9% and a total yearly costs exceeding 100 billion USD. The management of T2D presents considerable challenges in health and social care and poses a tremendous burden of costs on individuals and healthcare delivery systems [4].

The progression of T2D is characterised by an insidious onset and steady deterioration of health state over a long period of time during which a complex of comorbid health conditions such as problems with heart, kidney, sight, and lower extremities may appear [5]. Treatment of the chronic condition diabetes therefore requires long term, continuous and personalized care. Commonly, the larger part of health services for T2D, such as health promotion, health, education, diagnosis, regular monitoring, medication, check-up, is mostly performed by primary care professionals [6]. It is expected that the role of primary care professionals (as opposed to secondary care in hospitals and/or specialized physicians) will increase [7–9]. Most demand for T2D care is therefore serviced by primary care professionals such as GPs and nurses.

Due to the complexity and variety of T2D services, diabetes care typically involves multiple professionals to meet the demands of service users [10, 11]. Consequently, providers establish relationships with other providers to integrate the elements of the often fragmented service process [12]. This benefits different groups of stakeholders. In addition to being of interest to care providers, it is of interest to service users, informal care givers, insurers, and policy makers. It may smooth the flow of service delivery by eliminating overlaps, delays, misuse and overuse caused by fragmentation of service processes. Furthermore, it may help to contain costs [13].

T2D care providers operate within health service provisioning networks. These networks can be formed by means of explicitly defined relationships, and/or more implicitly as collections of providers jointly visited by (a population of) T2D patients. The public health system arising from the National Health Service in the United Kingdom (UK) is a prime example of explicitly regional organized provider networks with structural mechanisms for integration [14]. In the Netherlands for instance, a change in reimbursement schemes has encouraged a variety of regional networks to be formed [15]. Such networks include GPs, dieticians, specialists, laboratory services, etc [15]. Given the huge burden of disease T2D entails, and the importance of primary care networks for treatment, our research addresses the relationship between the operations of health service provider networks for T2D and the outcomes obtained.

In the present literature regarding the treatment of chronic diseases such as diabetes, the chronic care model [16, 17] plays a pivotal role. It constitutes a conceptual framework which encompasses essential mutually reinforcing components of integrated health service provisioning for the treatment of chronic diseases [18]. Since the early 2000s T2D studies embark on this model as a common guide for health service improvement. It has advanced the evidence base and understanding of the relationship between health service provisioning and outcomes, particularly regarding patient behaviour and self-management and their effects on outcomes (such as HbA1c level and quality of life) [19–21].

The chronic care model however does not provide a comprehensive and explicit model of T2D service operations. Conversely, existing literature regarding operations management of health service networks for T2D care provides little evidence regarding the relationship with outcomes. The Cochrane diabetes management review [22] reports studies considering both the diabetes service process and health outcomes, but does not consider provider networks as unit of analysis. A more recent review by Shojania and colleagues [9] analyses effects of operational strategies on diabetes outcomes, supporting evidence on the effectiveness of case management and team changes in improving glycaemic control. As summarized in their review most studies seem to consider only bounded elements of diabetes service operations rather than comprehensive network components. Mahdavi et al. [23] conclude more generally, in a systematic review on the use of operational models in healthcare, that the evidence base of operations management for effective health services is notably small.

Our research aims to enhance the understanding and evidence based for operations management in health service networks for T2D. More specifically we contribute to advancing the understanding of the interrelationships between operations and outcomes. The work is based on the EU FP7 project Managed Outcomes, and the corresponding framework and research methodology [24]. The framework and methodology enable a comparative analysis between regions and diseases, and supports further application and replication for future enhancement, thus responding to calls of Wagner et al. [16], Berwick [25], and the British Medical Council [26], to advance the scientific understanding of health service operations networks.

The outline of this study is as follows. In section Methods we present briefly the aforementioned framework and methodology and outline the study design and methods. Section Results presents the analysis and results. In section Discussion we discuss the analysis and results. In Section Conclusions we present our conclusions and recommendation for future research.

Methods

The present study is built on the framework for modelling and analysis methodology presented in Mahdavi et al. [24]. This methodology is applied to a multiple case studies' design with modelling and cross-sectional studies. This framework enables generally applicable and replicable models for health service operations to be developed. It offers a general platform on which to specify generic health service operation entities and a disease-specific basis on which entities can be added to the generic model, or redefined. Moreover, the models thus developed capture two types of instances: 'network instances' (which enable modelling of the networks); and 'health service user instances' (which enable modelling of the health service users). We refer to Mahdavi et al. [24] for a detailed description of the framework, and restrict the present paper to the modelling of provider networks for T2D services and health service users in these networks. In the remainder of the paper we refer to the disease-specific model for the network of health service operations for T2D as the 'diabetes model' and we use the term 'patients' rather than health service users. We also refer to the six network instances studied in the empirical FP7 study by the name of the region, e.g. Bamberg or Valencia.

The diabetes model inherits the five core entities for modelling of health service operations from the generic model: demand, services, structure, behaviour, and outcome (See Figure 4-1). The generic model captures the current scientific understanding that outcomes are not solely determined by service provisioning but also by health behaviour and health conditions (demand) interacting with the service provisioning processes and structures, with the result that service provisioning, health conditions and health behaviour jointly affect outcomes.

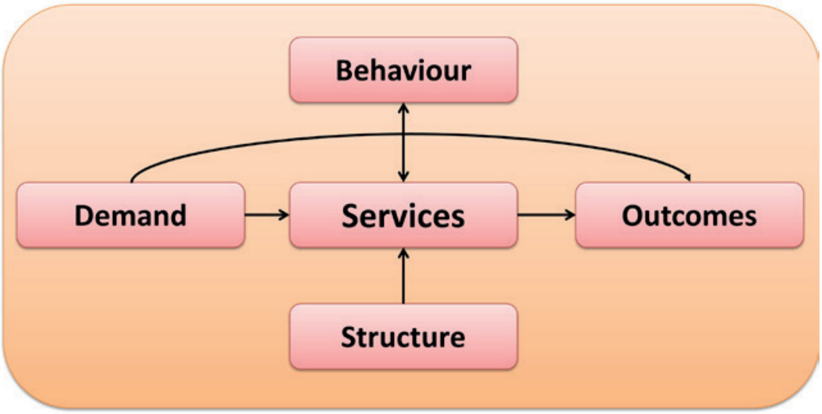

Figure 4-1 Relationships between demand, services, structure, behaviour and outcomes

Detail of the (generic) components of the 5 core entities of the operational model in Figure 4-1 is presented in Table 3-1.

The diabetes model

A network serves a population of T2D patients living in a region which is defined as a geographically bounded area that can be distinguished by 'demand locations'. Within a region, various categories of patients can be distinguished; these are referred to as 'demand segments'. We distinguish five segments for primary care services for type 2 diabetes patients according to international diabetes guidelines [5, 28]. These segments are: patients with high risk of developing diabetes (DS1); patients whose treatment solely consists of life style intervention (DS2); patients for whom life style intervention is combined with oral diabetic drugs (DS3) and patients for whom treatment comprises life style intervention, oral drugs, and/or insulin injections (DS4). The fifth demand segment (DS5) includes patients for whom the complexity of the treatment is such that the treatment is based in secondary care (rather than primary care – see Table 4-1).

Table 4-1 Specification of components for generic model for type 2 diabetes

Abstraction level Level 1	Level 2	Specified components for T2D
Demand	Demand location	Regions, urban areas, rural areas.
	Demand segments	High risk users (DS1)
		Users treated only by life style intervention (DS2)
		Users treated by life style intervention and diabetic drugs (DS3)
		Users treated by life style intervention, drugs, and/or insulin (DS4)
		Complicated diabetes patients (DS5)
	Diabetes service users	Age, gender, education, ethnicity, body mass index (BMI), age at diagnosis, time since diagnosis, family history of diabetes
Services	Services elements	First visit; Lab test outside lab; Lab test sampling; Lab test analysis; Visit for diagnosis and care plan; Etc.
	Service journeys	Screening (S1)
		Diagnosis (S2) + Diabetes treatment with life style advice (S3)
		Diabetes treated with life style advice and oral medication (S4)
		Diabetes treated with life style advice and/or oral medication and insulin therapy (S5) and (S6)1
	Service user journey	Screening (S1) diagnosis (S2); treatment with life style advice (S3) for DS2; treatment with life style advice and oral medication (S4) for DS3; treatment with life style advice and/or oral medication and insulin therapy (S5) and (S6) for DS4
Behaviour	Non-service related behaviour	Smoking, alcohol consumption, physical exercise
	Service co–creation behaviour	Knowledge of T2D clinical indicators (HbA1c, blood pressure, cholesterol) Adherence to the diabetic treatment: adherence to diet (for users in DS2), adherence to drug intake (for users in DS3) and adherence to insulin injection (for users in DS4)
Outcomes	Health outcomes	HbA1c level Complications: stroke, problems with heart, problems with sight, renal problems, problems with lower extremities
		Perceived health status (EQ-5D): mobility, self-care, usual activity, pain/discomfort, anxiety/depression Evaluation of health status in comparison with best and worst imaginable health status (Visual analogue scale of EQ-5D (VAS of EQ-5D)) Satisfaction with health status
	Service outcomes	Perceived service quality: tangibles, timeliness, responsiveness, empathy, caring, and communication (ServQual dimensions)
		Evaluation of service quality in comparison with best and worst imaginable services Satisfaction with service

The diabetes model also describes characteristics of the population of diabetes patients within different regions and demand segments. These include age, gender, educational attainment, ethnicity, body mass index (BMI), age at diagnosis, time since first diagnosis, stage of the disease, and family history of diabetes [29]. These variables capture differences in patients' characteristics which can lead to differences in outcomes [30].

Next, the diabetes model describes the entity services. Services are specified using service elements, service journeys, and service user journeys (Table 4-1). Service elements define the atomic units of service provisioning [31] such as a first visit to a GP or laboratory tests. A list of service elements used in the diabetes model is given in the additional file [27]. The service elements are based on the diabetes best practice guideline [5], and the list of service elements is common to all six regions investigated. An ordered set of service elements constitutes a 'service' which is defined in the regional instances. Services can be viewed as standards or guidelines which are commonly followed in a particular region, but they can differ between regions. 'Service journeys' are sets of one or more service elements offered to service patients in a demand segment. Each region has one service journey per demand segment, and which may comprise one or several service elements. From year to year, stable diabetes patients can repeat their service journeys, while for others the disease progresses and they move to a new service journey. Over time each patient therefore has a personal sequence of service journeys which we refer to as a 'service user journey'. Detailed descriptions of the services and service journeys for each region are provided in the additional file [27].

The transitions of patients between service journeys and hence between demand segments can be described using a Markov process [32] as shown in Figure 4-2. In this, the transition probabilities represent the relative number of patients per service journey who progress to subsequent service journeys (and demand segments). Empirically derived nonnegative transition probabilities may exist for transitions to preceding service journeys [33]. Transition probabilities differ between instances.

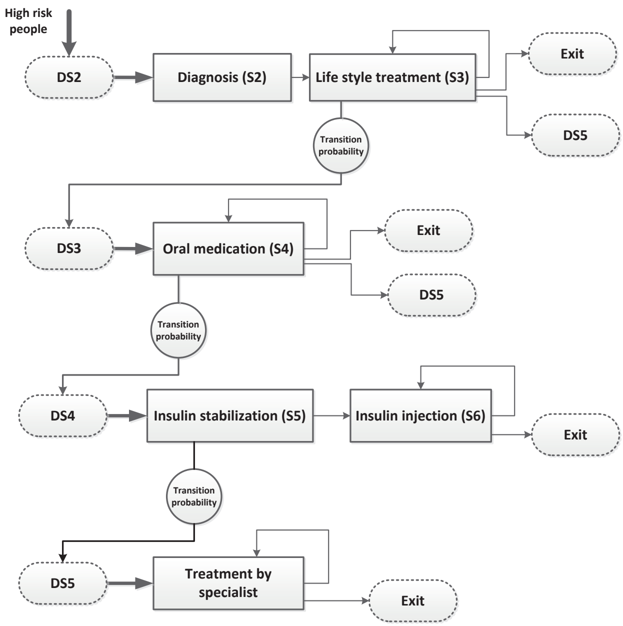

Figure 4-2 A Markov model representation of the diabetes service user journey

A further definition of the relevant dimensions of the services and the structures through which they are provided, such as resources [24], can be found in the additional file [27]. Among the process indicators to assess the service provisioning, we identify the transition probabilities between segments or, reciprocally, the length of stay (LOS) per segment [34]. The transition probabilities from DS2 to DS3 and DS4 as well from DS3 to DS4 are considered to be important (intermediate) outcomes of health operations in maintaining the health state of the diabetes patient. A longer LOS in DS2 and a larger proportion of patients in this segment is considered a more favourable outcome.

Health behaviour is defined by non-service related behaviour and service co-creation behaviour. Non-service behaviour includes smoking, alcohol consumption, and physical exercise [29]. Co-creation behaviour concerns adherence to treatment (i.e. diet, diabetic drug intake, and insulin injection) and knowledge of personal clinical indicators i.e. HbA1c value, blood pressure, and cholesterol [35–37] (Table 4-1).

The outcomes are of two types: 'health' and 'service' outcomes. Diabetes-specific outcomes are disease specific such as HbA1c level and prevalence of comorbidities or complications, e.g. diabetic retinopathy, heart disease [38, 39] (Table 4-1). In addition, the diabetes-specific model defines the perception and evaluation of the health status and services by the service users as service outcomes [40]. Note that the clinical outcomes - such as HbA1C level - can be seen as determinants of both health status and satisfaction (as illustrated for five regions in European countries in Figure 4-3, and hence as an intermediary outcome variable.

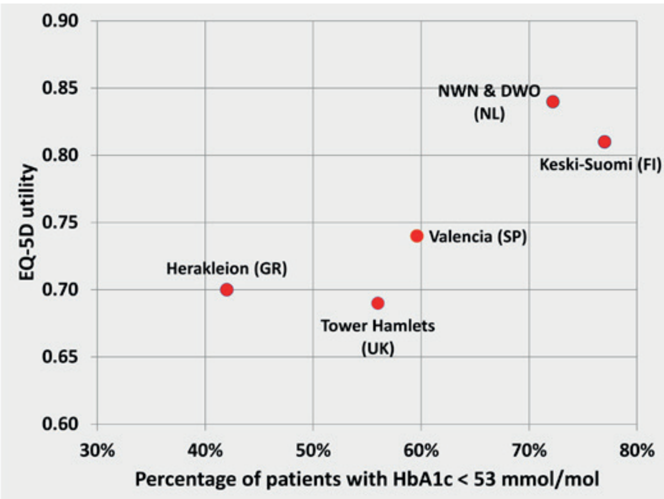

Figure 4-3 Illustration of relationships between intermediate outcomes and quality of life for type 2 diabetes patients

Instances of regional provider networks

We next define an instance of the diabetes model for each of six European regions considered in our study. The regions are: Keski-Suomi (Finland); Bamberg (Germany);

Herakleion (Greece); NieuweWaterwegNoord & DelftWestlandOostland (NWN & DWO) (The Netherlands); Valencia (Spain); and Tower Hamlets (United Kingdom) (see Table 4-2) and data were sourced for each of these during the years 2011-2012. The selection of the countries and regions was not randomized or relied on a priori knowledge of any innovation, adoption of evidence-based standards, or of best practice recognition, but was based on pragmatic arguments and, importantly, local interest and willingness to cooperate.

Most of the values that define instances are means and averages for the respective diabetes networks collected from medical information systems and patient records or through the patient survey conducted as a key component of the Managed Outcomes project. A more detailed description of the region instances can be found in the additional file [27].

Samples of T2D patients studied in Bamberg, Herakleion, and Valencia were surveyed in the second half of 2011 and in the other regions in the first half of 2012. An appropriate sample of institutions in each network (e.g. health centre or general practitioner surgery) was chosen to participate in the survey (See Table 4-2).

Table 4-2 Overview of the T2D regional provider networks

	Keski-Suomi (FI)	**Bamb-erg (GE)**	**Herakle-ion (GR)**	**NWN & DWO (NL)**	**Valencia (SP)**	**Tower Hamlets (UK)**	**Total**
Region size (km2)	16,706	1,223	2,641	273	135	21	20,999
Population serviced by network	272,784	214,269	299,689	330,464	202,621	233,329	1,553,156
People over 40 years (%)	53	55	47	49	49	28	281
Number of T2D patients in region	17,567	3,943	21,362	12,218	10,724	11,203	77,017
Participating health facilities in survey	9	5	4	5	1	7	31
Questionnaires distributed	436	462	600	779	625	3,070	5,972
Questionnaires returned	183	286	179	400	115	475	1,638
Questionnaires included in analysis	183	282	179	387	115	313	1459
Response rate (%)	42.0	61.9	29.8	51.3	18.4	15.5	27.4

The recruitment of participants was constrained by several limitations defined by the health care providers investigated. Moreover, several different statistical tests with different properties were intended to be used. So an exact a-priori determination of the sample size is neither of much use nor possible. However, to get a hint as to which sample size should at least be aspired we determined the sample size which would be needed for an ANOVA performed for the six different regions to be compared. To this purpose, we used a statistical power package G*Power [41]. The sample size was determined for a small effect size ($f = 0.10$) [42], α equal to 0.05, and statistical power equal to 0.80. Based on these assumptions, total sample size was 1284 patients. Taking the safe side because of a small response rate, 5,972 questionnaires were distributed. In average per region (except Tower-Hamlets) 600 questionnaires were sent to patients (Table 4-2). In Tower-

Hamlets because of poor socio-economic characteristics of population and possibility of lower response rate, a larger number of questionnaires are sent to the patients.

Instruments and data collection in case instances

The diabetes model presents a comprehensive set of variables for analysis of T2D operations and outcomes. We used three sources to collect data for operations, behaviour, and outcomes: medical information systems and patient records; patient questionnaires and interviews with local staff. Below we describe the data collection procedures and instruments.

Operations (service and structure) data for each regional instance was collected by interview requests for data from existing local information systems (see Table 4-2). A standardized spreadsheet model was developed which captured the diabetes model and corresponding calculations (see the additional file [27]).

Data on demand characteristics, behaviour, and outcomes was collected by approaching type 2 diabetes patients living in the regions via a survey which, amongst other things, asked for age, gender, education, time since diagnosis, and diabetes stage (demand segment) of participants. In order to be included in the survey patients must be treated only by primary care networks or non-hospital based settings. Aspects of behaviour and health state/quality of life are given in Table 4-3.

Table 4-3 Operations, behaviour, and outcomes

Operations	Behaviour	Intermediate outcomes	Outcomes
Frequency of services [1] Frequency of service elements by service [1] Frequency of follow up visit [1 2] Duration of service [1] Duration of service elements by service [1] Perceptions of the comprehensiveness of follow up visit [2] Resource type [1] Volume of services (frequency x duration)[1] Volume of service elements per service [1] Access time to service [2] Waiting time for visits [2] Costs of service element, service journey, and service user journey [1] Operational service quality [2] Length of stay in each demand segment [1] Transition probabilities [1]	Alcohol consumption [2] Smoking [2] Physical activity[2] HbA1CKnown [2]	Percentage of patients with HbA1c<53 mmol/mol [1 2]	Health status (EQ-5D-utility, Dolan index) [2] Satisfaction with health [2] Perceived service quality [2] Service Satisfaction [2] Complications [12]

[1] operational model, [2] Survey

The percentage of patients with HbA1c<53 mmol/mol was collected from provider information systems and patient records, but the HbA1c level was also asked for in the survey. Data on complications was collected from provider information systems and patient records, but also addressed in the survey. The EuroQol instrument (EQ-5D (‘five dimensions’)) which had validity and reliability across all regions was used to measure the perception of the patients of their health conditions [43]. The perception of service quality was measured by a short, generic version of the SERVQUAL instrument [44] which includes six aspects of quality: tangibles, timeliness, responsiveness, empathy, caring and communication. Satisfaction with services was captured by a single question which measured satisfaction on a scale from 'extremely dissatisfied' to 'extremely satisfied'. The patient survey also sought data on the perceived aspects of operations: traveling time to and distance from the main provider offices or clinics; waiting time in the provider office or clinic; frequency of visits in a one year period; and the patient's perception of the comprehensiveness of consultation.

The questionnaire was developed in English and then translated into the native language of each region [45]. Two native speakers of the target region's language translated it from English, and one native English speaker translated it back from a target language to English to ensure its validity. The questionnaires were also culturally adapted where necessary.

The study was approved in each country. The Keski Suomi study was approved by the Ethics Committee of the Central Finland Health Care District, the Bamberg study was approved by the Ethics Committee of the Medical Faculty of the Friedrich-Alexander University in Erlangen-Nürnberg, the Herakleion study was approved by the Scientific Committee of the hospital in Herakleion, the NieuweWaterwegNoord & DelftWestlandOostland study was approved by the board of directors of the Primary Care Group ZEL, the Valencia study was approved by the Hospital La Fe Ethical Committee and the Tower Hamlets study was approved by the NHS National Research Ethics Service. Permission for use of data was received from the Ethics Committee of the Central Finland Health Care District (statistical data at aggregate level), the Ethics Committee of the Medical Faculty of the Friedrich-Alexander University in Erlangen-Nürnberg (statistical data at aggregate level), the Scientific Committee of the hospital in Herakleion (statistical data and access to patient records), the Scientific Council of the IPCI system of the department of Medical Information of the Erasmus Medical Centre (statistical data at aggregate level), the Hospital La Fe Ethical Committee (statistical data at aggregate level) and the NHS National Research Ethics Service (statistical data and access of patient records through the clinicians of the local diabetes research network).

On behalf of the Managed Outcomes project health authorities with a right to access patient information sent questionnaires to patients. The questionnaire also included research information and an invitation to participate in this research. Completion of the survey by patients was entirely voluntary. All personal patient identifiers were removed or disguised so the respondent was not identifiable either through the measurements they provided or through any free text provided for the open questions. As there was no patient identifiable data on the survey form it was not possible to follow-up any non-respondents.

The questionnaire was given to the patients by their GP or primary care team member with whom the user was registered. In Herakleion questionnaires were mailed to patient addresses. In total 5,972 patients in 31 health facilities across all regions were approached. One thousand six hundred and thirty eight questionnaires were returned, i.e. there was a response rate of 27.4% (See Table 4-2).

Analysis methods

The diabetes model enabled descriptions of six regional instances and their subsequent comparison. The main purpose of our research is however to understand the relationships between operations and outcomes and the analysis methods we use for this purpose follow the methodology provided in Mahdavi et al. [46].

We begin with a brief explanation of the use of an observational multiple case study design forming a small cohort of networks. On one hand this design is more robust than the single case studies often encountered in the literature on both health service operations management and health services research but, on the other, the design lacks a 'controlled' intervention and a control group, thus making it harder to attribute differences in outcomes to differences in operations. Our choice has been based on practical arguments; it allows for a respectable form of data collection and analysis efforts in six European countries in a standardized manner. Moreover, it supports future application in other regions and/or follow-up studies in the same regions due to its ease of implementation [47]. The design has been argued to contribute to advancing evidence based operations management in health service provider networks [48].

The methodology proposed in Mahdavi et al. [24] consists of two related steps. The first of these systematically explores notable differences in outcomes between the regional instances and their interrelationships with any notable differences in operations. Rather than mining for interrelationships with every possible operational variable, the analysts propose operational variables per outcome variable, based on theory, scientific evidence, or expert opinion. In the second step the methodology systematically considers notable differences in operations and considers the interrelationships with any notable differences in outcomes. Again it is up to the analysts to propose related outcome variables for each operational variable for which notable differences occur. Whenever possible, a 'notable difference' has statistical significance. A list of relevant operations and outcomes variables is given in Table 4-3.

Table 4-3 presents a list of operational dimensions in the case instances. For the purpose of this paper we do not present exhaustive results, but only those results we consider to be of scientifically highest relevance.

To identify notable differences in both outcomes and operations we rely on one way analysis of variance (one-way ANOVA) where possible [49]. In the majority of analyses we use hierarchical regression models for testing hypotheses. In the first step of the analyses the demand variables age, gender, education, and time since diagnosis are entered, in the second step also behaviour, and in the further steps variables describing operations and/or context.

As quality of life as measured with the EQ-5D is a core variable in the analyses participants who answered less than 4 of the 5 EQ-5D questions were excluded from analyses. For those participants who answered exactly 4 questions the answer for the remaining fifth question was imputed using the country specific median for this question. For the remaining variables investigated missing values were imputed using the multiple imputation procedure of SPSS. Five different completed datasets were produced using this approach. All analyses were performed as far as possible with the completed datasets. Accordingly, for the regression analyses, pooled unstandardised regression coefficients and the corresponding tests based upon the corresponding pooled standard errors. For the other relevant statistics no adequate procedures for pooling over the different completed data sets are known at the present. So, for these statistics, different variants were reported: on the one hand the statistics for the data set comprising only cases without missing data and on the other hand the ranges of the statistics for the five different completed data sets. As long as data are missing completely at random inferential tests performed only for the complete data are more conservative as a true test would be whereas the tests performed for the completed data are more liberal. So the true statistical test result can be assumed between both of them.

Statistical analyses were performed using the IBM SPSS statistical package version 20.

Results

The results of the study consider the analysis of operations and outcomes for the population of T2D patients in the regions according to the two step approach outlined above. The differences in operations are considered using operational models from five of the six case instance regions (Bamberg did not collect operational data), but the majority of outcomes are derived from the survey with responses from 1,638 T2D patients (i.e. covering all six case instance regions including Bamberg). However, some of these patients had to be excluded from the analyses because they did not sufficiently master the language in which the questionnaire was formulated. So, only 1459 participants could be included into the analyses. The data set supporting the results of this article is included within the article and its additional file [27]. A summary of demographic characteristics of participants is also presented online in an additional file of this paper.

From differences in outcomes to differences in operations

Table 4-4 presents selected outcome variables from the six region specific instances in the Managed Outcomes project. Table 4-4 does not include results for all outcome variables in Table 4-3 due to our limitation of the number of hypotheses for this paper. As a result, we analyse three distinct outcome variables. Firstly, a commonly encountered prime clinical outcome variable which measures the effective control of the HbA1c level [50]. Secondly, a health outcome variable which relies on the EQ-5D model, as considered in previous diabetes research [22].

The third outcome variable is ‘satisfaction with services’. To form hypotheses about the relationships between the notable differences in these outcomes and operations we use the most recent Cochrane systematic literature review on diabetes [22], other reviews on diabetes service management [9, 51], and assessments from the researchers and practitioners involved in our case studies.

One notable difference is in the proportion of patients with effective glycaemic control. With 77%, Keski-Suomi has the highest proportion of effectively controlled patients whereas, with 42%, Herakleion has the lowest. From a Chi-square test, these differences appear to be highly significant ($p<0.001$). Below we consider differences in service use and costs and how such differences can explain for the differences in HbA1c.

Table 4-4 Health outcomes

	Keski-Suomi (FI)	Bamberg (GE)	Herakleion (GR)	NWN & DWO (NL)	Valencia (SP)	Tower Hamlets (UK)	Total	Welch F[1]	Df1	Df2
Patients with HbA1c<53 mmol/mol	77	NA	42	72	60	56	61			
EQ-5D utility[2]										
Mean	0.81	0.76	0.7	0.84	0.74	0.69	0.77	25.1*	5	514.4
SD	0.17	0.2	0.2	0.17	0.24	0.27	0.22			
95% CI[3]	0.78	0.74	0.67	0.83	0.7	0.66	0.75			
	0.83	0.79	0.73	0.86	0.79	0.72	0.78			
N	181	271	174	379	110	304	1419			
Services satisfaction[4] (Statistics for cases without missing values)										
Mean	86.82	79.33	70.81	86.25	69.18	77.38	79.84	18.5*	5	494.7
SD	19.01	24.58	26.15	20.36	26.71	25.46	24.22			
95% CI	83.96	76.31	66.84	84.14	64.04	74.46	78.55			
	89.68	82.34	74.78	88.36	74.33	80.3	81.13			
N	172	258	169	360	106	294	1359			
Services satisfaction (Statistics for data with missing values imputed)										
Mean	86.96	79.2	71.03	86.06	68.3	77.44	79.75	18.8-21.0*	5	531.4-533.9
SD	19.15- 0.36	23.88-24.81	25.67- 26.67	20.70- 21.25	26.14-26.72	25.10- 25.64	24.32-24.48			
95% CI	83.59-84.67	75.70-76.92	66.30-67.56	83.68-84.14	63.06-63.90	74.33-75.10	78.34-78.77			

Table 4-4 Health outcomes (continued)

	Keski-Suomi (FI)	Bamberg (GE)	Herakleion (GR)	NWN & DWO (NL)	Valencia (SP)	Tower Hamlets (UK)	Total	Welch F[1]	Df1	Df2
	89.22-90.25	81.52-82.61	74.1-75.4	87.88-88.33	72.81-73.56	79.92-80.80	80.85-81.28			
N	183	282	179	387	115	313	1459			

Note: *** p<.001

[1] Welch F test is reported as differences in variance between regions are significant.

[2] EQ-5D-utility is calculated according to Dolan. This scale is standardized with 0 for death and 1 for full health. Missing values of EQ-5D dimensions are imputed only if at most one dimension was missing.

[3] 95% CI=95% confidence interval (the first line shows lower bound and the second line shows upper bound).

[4] This scale is standardized from 0 to 100.

For the other outcome variables Table 4-4 reveals that statistically significant differences (on the basis of one way ANOVA) exist between the regions in EQ-5D utility and service satisfaction.

Table 4-5 shows that there are significant differences between regions with regard to the EQ-5D after controlling for effects of demand and behaviour. The post hoc analysis performed shows that Herakleion significantly differs from all of the others; Valencia appears to differ from Bamberg and Keski-Suomi and in turn NWN&DWO differs with the others. Among several operational dimensions that are reported to influence EQ-5D utility, human resources are reported as most important [9]. More recent evidence indicates that when a larger role in diabetes care is given to nurses (e.g. nurse practitioner or a specialised diabetes nurse) instead of GPs patients obtain better health outcomes [52, 53]. We therefore consider types of human resource and hypothesize that:

H1: Higher EQ-5D utility is positively associated with an increased role of nurses in the service provisioning.

Hänninen et al. [54] find evidence supporting a positive relationship between the frequency of regular follow–up visits on one hand and EQ-5D on the other. Based on this evidence we hypothesize that an increased number of follow up visit is associated with higher EQ-5D utility:

H2: Higher EQ-5D utility is positively associated with the number of follow up visits.

We now turn to the outcome variable satisfaction with services.

Table 4-6 shows that significant differences remain between the regions after controlling for demand and behaviour. Herakleion has significantly lower service satisfaction than Tower Hamlets, whereas the other regions have significantly higher satisfaction, with NWN&DWO in particular standing out. Tower Hamlets was used as benchmark.

To explain for the differences we first turn to more general service quality dimensions as proposed in the Service Quality Gap Model [55] and its adaptation for health services by Bowers et al. [56]. More specifically, we observe that these authors found that the perceived operational service quality (POSQ) dimensions of tangibles, timeliness, responsiveness, empathy, caring, and communication are determinants of satisfaction with services and hypothesize that:

H3: There are positive relationships between (perceived) tangibles, timeliness, responsiveness, empathy, caring and communication and service satisfaction.

The association between human resources and EQ-5D utility

To test hypothesis *H1* regarding the effects of human resources on EQ-5D utility, we observe three resource models, practiced among the five regions for which the operational model is elaborated [24]. In Herakleion, GPs and hospital doctors (GP/internist model, Model 1) take the prime role, and nurses have a marginal role. In Valencia and Bamberg, GPs or family doctors have the main role while a few hours of care are delivered by nurses (GP/Family doctor model, Model 2).

Table 4-5 Hierarchical regression analysis of EQ-5D [a]

Step	Variables	β Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
1	Age	-.002**	-.003**	-.003**	-.003**	-.003**	-.003**
	Gender [b]	.073**	.078**	.067**	.067**	.067**	.065**
	Education [c]	.064**	.025	.015	.015	.014	.011
	Time since diagnosis	-.002*	-.002*	-.001	-.001	-.001*	-.001*
	Demand segment 2	.055**	.050**	.046*	.044*	.046*	.047**
	Demand segment 3 (reference)						
	Demand segment 4	-.059**	-.060**	-.060**	-.057**	-.058**	-.055**
2	Tower-Hamlets		-.148**	-.121**	-.123**	-.118**	-.111**
	Keski-Suomi		-.023	-.018	-.023	-.022	-.018
	Bamberg		-.049**	-.055**	-.053**	-.049**	-.026
	Herakleion		-.114**	-.111**	-.109**	-.101**	-.058*
	Valencia		-.059**	-.046*	-.045*	-.033	-.014
	NWN&DWO (reference)						
3	Alcohol consumption [d]			.042	.041**	.041**	.037**
	Smoking [e]			-.038	-.037*	-.036*	-.037*
	Physical activity			.002	.002*	.002*	.002*
	HbA1CKnown [f]			.045	.046**	.044**	.043**
4	Number of follow-up visits				-.003*	-.004*	-.005**
5	Comprehensiveness of follow-up visits					.012**	.012**
6	Travelling distance(km)						.000
	Travelling time (minutes)						-.001
	Waiting time in office (minutes)						-.001**
Statistics for cases without missing values							

4

Table 4-5 Hierarchical regression analysis of EQ-5D [a] (continued)

Step	Variables	β Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
	ΔR^2		.08	.02	.01	.00	.01
	R^2	.13	.21	.23	.24	.24	.25
	Δf	17.94**	14.95**	5.15**	11.42*	0.60	4.30*
	df1	6	5	4	1	1	3
	df2	742	737	733	732	731	728
	P value of Δf	.000	.000	.000	.001	.440	.005
Statistics for data with missing values imputed							
	ΔR^2		0.06	0.03	0.00	0.00	0.01
	R^2	0.11-0.12	0.17-0.18	0.2✝	0.20-0.21	0.21✝	0.22✝
	Δf	28.73-31.78	19.19-20.26	11.61-13.79	3.31-5.43	6.37-8.75	5.09-8.55
	df1	6	5	4	1	1	3
	df2	1412	1407	1403	1402	1401	1398
	P value of Δf	.000✝	.000✝	.000✝	.020-.069	.003.012	.000-.002

[a] EQ-5D measured with 1 utility of full health and 0 utility of death. Unstandardized coefficients, *p<.05; **p<.01.

[b] 0=female, 1= male.

[c] 0= minimum school leaving age, 1= more than minimum school leaving age.

[d] 0= No alcohol consumption, 1= alcohol consumption.

[e] 0= Non-smoker and former smoker, 1= smoker.

[f] 0= HbA1c not known, 1= Hba1c known.

✝ Minimum and maximum values are equal.

Table 4-6 Hierarchical regression analysis of satisfaction with services [a]

Step	Variables	β						
		Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
1	Age	.07	.06	.05	.02	.02	.04	.03
	Gender [b]	2.88*	2.65	3.43*	3.46*	3.38	3.40*	3.30
	Education [c]	5.26	4.45**	1.16	.87	.82	.55	.50
	Time since diagnosis	-.02	-.01	.04	-.02	-.01	-.03	-.03
	Demand segment 2	.13	.05	-1.58	.67	.88	1.20	1.11
	Demand segment 3 (reference)							
	DemandSegment4	-.32	-.44	-.68	-1.92	-2.30	-2.35	-2.36
2	Alcohol consumption [d]		1.42	-1.21	-1.63	-1.50	-1.55	-1.54
	Smoking [e]		-2.50	-1.92	-2.06	-2.18	-2.01	-2.16
	Physical activity		.13	.16	.04	.03	.01	.00
	HbA1CKnown [f]		2.82	4.26*	1.28	1.21	1.05	1.03
3	Tower-Hamlets			-6.81**	-3.33*	-3.06	-2.22	-2.77
	Keski-Suomi			.80	1.77	2.43	2.42	1.85
	Bamberg			-7.67**	-7.91**	-8.19**	-7.30**	-6.05**
	Herakleion			-16.03**	-6.30**	-6.69**	-5.83**	-5.24*
	Valencia			-17.88**	-9.78**	-10.01**	-8.17**	-7.58**
	NWN&DWO (reference)							
4	Tangibles				2.57**	2.58**	2.31**	2.31**
	Timeliness				1.45	1.46	1.45	1.37
	Responsiveness				3.48**	3.56**	3.17**	3.19**
	Empathy				-2.19*	-2.19*	-1.65	-1.63
	Caring				2.99*	3.02	2.74*	2.70*
	Communication				1.87**	1.71*	1.45*	1.46*
5	Number of follow-up visits					.45**	.29	.27
6	Comprehensiveness of follow-up visits						2.69**	2.56**
7	Travelling distance(km)							-.04

Table 4-6 Hierarchical regression analysis of satisfaction with services [a] (continued)

Step	Variables	β Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
	Travelling time (minutes)							.10
	Waiting time in office (minutes)							-.05**
Statistics for cases without missing values								
	ΔR^2	.02	.01	.06	.34	.00	.01	.01
	R^2	.02	.03	.09	.43	.43	.44	.45
	Δf	2.70	1.60	8.27	64.93	0.05	15.74	2.29
	df1	6	4	5	6	1	1	3
	df2	677	673	668	662	661	660	657
	P value of Δf	.013	.172	.000	.000	.823	.000	.078
Statistics for data with missing values imputed								
	ΔR^2	0.01- 0.02	0.00- 0.01	0.05 - 0.06	0.32-0.34	0.00	0.01- 0.02	0.00-0.01
	R^2	0.01-0.02	0.02- 0.03	0.07- 0.08	0.040-0.42	0.40-0.43	0.42- 0.44	0.43- 0.45
	Δf	3.55-4.33	1.61- 3.75	16.44-18.64	127.83-142.02	6.47-11.21	30.11- 44.71	3.05- 4.52
	df1	6	4	5	6	1	1	3
	df2	1452	1448	1443	1437	1436	1435	1432
	P value of Δf	.000- .001	.005-.167	.000	.000	.001- .011	.000	.004-.027

[a] Service satisfaction measured on a scale ranging from 0 to 100. Unstandardized coefficients, *p<.05; **p<.01. [b] 0=female, 1= male.
[c] 0= minimum school leaving age, 1= more than minimum school leaving age. [d] 0= No alcohol consumption, 1= alcohol consumption.
[e] 0= Non-smoker and former smoker, 1= smoker. [f] 0= HbA1c not known, 1= HbA1c known.

The largest role for nurses is in Keski-Suomi and NWN&DWO where services are provided mostly by nurses, supervised by GPs (collaborative GP/nurse model, Model 3). (See the additional file for the explication of these roles in the resource and service modelling [27]).

Hypothesis *H1* is tested using multiple regression models in Table 4-7. As the variable 'human resources' is not independent from the regional variables included in the aforementioned models to capture context, these regional variables cannot be added to the model [24]. Thus, the second analysis step as presented above which controls for the effects of regions as context is now omitted.

As shown in Table 4-7, inclusion of the resource models in the analyses significantly increases the explained variance of EQ-5D with control for demand and behaviour. In fact, this model explains as much variance as the model where the regions are considered separately. Model 3 ($\beta=0.12$, $p<.01$) is associated with a significant improvement in EQ-5D utility. These findings indicate that when care is provided by model 3 the improvement is twice the improvement in model 2 and 10 times the improvement by model 3. This analysis proves hypothesis H1 that more use of nurses improves quality of life of diabetes patients. These findings confirm the evidence of Collins et al. [53] and Houweling et al. [57] that the GP/nurse model and more use of nurses compared to the other models generates significantly higher EQ-5D utility. The amount of change in quality of life is remarkably high compared with a marginal improvement in intermediate outcome (HbA1c) [52].

4

The association between follow up visits and EQ-5D utility

To test hypotheses *H2* regarding relationships between the follow up visit and EQ-5D utility, we first notify that there are significant differences between regions with regard to the number of follow-up visits (Table 4-8).

Multiple regression models are presented in Table 4-5 to test hypothesis *H2*. In step 4, the regression coefficients for 'number of visits' are calculated, controlling for the variables already added in step 1-3. NWN&DWO is the benchmark for comparison between regions in step 2. Furthermore, hypothesis *H2* is tested in Table 4-7 in a slightly different manner. Now, instead of regions effects of the resource models are controlled in order to accumulate effects of variables.

From the regression we see that an increase in the number of follow-up visits by one visit per year is associated with 0.003 decreases in the EQ-5D. Therefore we reject the hypothesis *H2* that an increase in the number of follow up visits is associated with an increase in EQ-5D utility (Step 4 in Table 4-5 and Table 4-7). The association found is in the opposite direction. We explicitly stress here that the presented relationships are not necessarily causal relationship where operations explain outcomes. The findings contradict evidence of Hänninen et al. [54] that better health outcomes are associated with more use of services. The findings do support evidence of Shalev et al. [58], however, that poor health outcomes are associated with increased health service use.

Table 4-7 Hierarchical regression analysis of EQ-5D [a]

Step	Variables [1]	β Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
1	Age	-.002**	-.002**	-.003**	-.003**	-.003**	-.003**
	Gender [b]	.073**	.059**	.066**	.067**	.067**	.065**
	Education [c]	.064**	.044**	.016	.017	.015	.011
	Time since diagnosis	-.002*	-.001	-.001	-.001	-.001*	-.001*
	Demand segment 2	.055**	.051**	.048**	.047**	.049**	.049**
	Demand segment 3 (reference)						
	DemandSegment4	-.059**	-.059**	-.061**	-.059**	-.060**	-.056**
2	Alcohol consumption [d]		.056**	.042**	.041**	.041**	.037**
	Smoking [e]		-.044**	-.037*	-.037*	-.036*	-.037*
	Physical activity		.003**	.002*	.003*	.002*	.002*
	HbA1CKnown [f]		.048**	.044**	.045**	.043**	.042**
3	Model 1, GP/internist			.010	.015	.017	.054*
	Model 2, GP/family doctor			.069**	.072**	.074**	.089**
	Model 3, GP/nurse			.115**	.115**	.111**	.105**
4	Number of visits				-.003	-.004*	-.004**
5	Comprehensiveness					.012**	.012*
6	Travelling distance(km)						.000
	Travelling time (minutes)						-.001
	Waiting time in office (minutes)						-.001**
Statistics for cases without missing values							
	ΔR^2		.03	.07	.01	.00	.01

Table 4-7 Hierarchical regression analysis of EQ-5D [a] (continued)

Step	Variables [1]	β Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
	R^2	.13	.16	.23	.24	.24	.25
	Δf	17.94	7.67	21.04	10.21	0.48	4.56
	df1	6	4	3	1	1	3
	df2	742	738	735	734	733	730
	P value of Δf	.000	.000	.000	.001	.486	.004
Statistics for data with missing values imputed							
	ΔR^2	0.11- 0.12	0.04- 0.05	0.04✝	0.00✝	0.00✝	0.01✝
	R^2	0.11- 0.12	0.16-0.17	0.20✝	0.20- 0.21	0.20 -0.21	0.21- 0.22
	Δf	28.73- 31.78	17.46-20.70	22.32-24.89	2.83-4.81	6.09- 8.44	5.41 - 8.78
	df1	6	4	3	1	1	3
	df2	1412	1408	1405	1404	1403	1400
	P value of Δf	0.000✝	0.000✝	0.000✝	0.028-0.093	0.004-0.014	0.000-0.001

[a] EQ-5D measured with 1 utility of full health and 0 utility of death. Unstandardized coefficients, *p<.05; **p<.01.

[b] 0=female, 1= male.

[c] 0= minimum school leaving age, 1= more than minimum school leaving age.

[d] 0= No alcohol consumption, 1= alcohol consumption.

[e] 0= Non-smoker and former smoker, 1= smoker.

[f] 0= HbA1c not known, 1= HbA1c known.

✝ Minimum and maximum values are equal.

Table 4-8 Number of and comprehensiveness of follow up visits

	Keski-Suomi	Bamberg	Herakleion	NWN & DWO	Valencia	Tower Hamlets	Total	Welch F[1]	Df1	Df2
Comprehensiveness of follow up visits (Statistics for cases without missing values)										
Mean	4.24	4.16	3.87	4.38	3.47	3.84	4.07	12.96*	5	486.72
Std. Error	0.08	0.07	0.1	0.06	0.14	0.08	0.03			
SD	0.99	1.12	1.35	1.05	1.48	1.29	1.22			
95% CI	4.09	4.02	3.66	4.28	3.18	3.69	4.01			
	4.39	4.3	4.07	4.49	3.75	3.99	4.14			
N	166	256	171	362	105	286	1346			
Comprehensiveness of follow up visits[2] (Statistics for data with missing values imputed)										
Mean	4.26	4.17	3.86	4.35	3.46	3.83	4.06	12.88-4.61*	5	528.91-31.78
Std. Error	0.08	0.07	0.11	0.06	0.14	0.07	0.03			
SD	0.98-1.04	1.12-1.14	1.33-1.4	1.06-1.11	1.43- .47	1.29-1.31	1.23-1.23			
95% CI	4.08-4.15	4.01-4.06	3.61- 3.69	4.23-4.26	3.14-3.22	3.68-.69	3.99-4.01			
	4.38- 4.44	4.27- 4.33	4.03 - 4.08	4.45-4.47	3.68-3.76	3.97-3.98	4.11-4.14			
N	183	282	179	387	115	313	1459			
Number of follow up visit (per year) (Statistics for cases without missing values)										
Mean	2.45	4.37	4.59	3.66	4.08	2.96	3.66	32.56*	5	459.45
Std. Error	0.11	0.16	0.27	0.07	0.35	0.13	0.07			
SD	1.38	2.63	3.57	1.29	3.54	2.13	2.46			
95% CI	2.24	4.05	4.05	3.53	3.39	2.7	3.52			
	2.66	4.7	5.13	3.8	4.77	3.22	3.79			
N	167	257	171	358	103	268	1324			
Number of follow up visit (per year) (Statistics for data with missing values imputed)										
Mean	2.47	4.36	4.6	3.65	4.01	2.93	3.63	29.06-	5	508.43 -

Table 4-8 Number of and comprehensiveness of follow up visits (continued)

	Keski-Suomi	Bamberg	Herakleion	NWN & DWO	Valencia	Tower Hamlets	Total	Welch F[1]	Df1	Df2
Std. Error	0.12	0.17	0.27	0.08	0.33	0.12	0.07	34.84*		12.83
SD	1.39- 1.57	2.6- 2.64	3.51- 3.55	1.41- 1.47	3.42- 3.49	2.14- 2.23	2.46-2.5			
95% CI	2.18-2.33	3.98- 4.15	4.03 -4.13	3.46- 3.55	3.27- 3.45	2.67- 2.72	3.47-3.53			
	2.63- 2.75	4.59- 4.77	5.07- 5.18	3.75-3.83	4.54-4.72	3.16-3.19	3.72-3.79			
N	183	282	179	387	115	313	1459			

Note: *p<.001

[1] Welch F test is reported as differences in variance between regions are significant.

[2] Assessed with five-category scale anchored with ‘never’ and ‘always’.

✝ Minimum and maximum values are equal.

The association between service quality and satisfaction with services

Hypothesis *H3* is tested using hierarchical regression models in Table 4-6 and Table 4-9. Before including aspects of follow up visit, access, and the perceived operational quality into analyses, effects of demand, behaviour, and regional context on satisfaction with services are controlled from step 1 to step 3 in Table 4-6. Again step 3 in Table 4-6 is slightly different to step 3 in Table 4-9. Table 4-6 controls the six regions as context in step 3 and further whereas Table 4-9 controls resource models.

Considering the Step 1 models, we notice that they explain about 2% of the variance in service satisfaction (while they explained 12% of the variance in EQ-5D). As was the case when considering EQ-5D, adding the regions (or the human resource models) explains an additional 6% of variance in satisfaction with services.

Before presenting results regarding *H3* we compared regions with regard to the corresponding service quality dimensions and established that significant differences between regions exist, using one-way ANOVA [27]. Step 4 in both Table 4-6 and Table 4-9 illustrates relationships between these differences in the service quality dimensions and differences in the satisfaction. This analysis shows that inclusion of the service quality dimensions increases explained variance in the satisfaction with services by about 34% and therefore confirms *H3*. This change in the amount of explained variance in service satisfaction is similar to a study by Vinagre et al. which report a direct effect ($\beta=0.37$, $p<.001$) of health service quality dimensions on service satisfaction [59].

The service quality dimensions (tangibles, timeliness, responsiveness, empathy, caring, and communication) are significantly related to service satisfaction. The association between responsiveness and satisfaction (unstandardized $\beta=3.48$, $p<.01$) in Table 4-6 and association between caring and satisfaction (unstandardized $\beta=3.25$, $p<.01$) in Table 4-9 stand out. These contributions are larger than the contributions reported by other studies, for instance Senic et al. [60].

The significant negative association between empathy and service satisfaction contrasts with the other five items and with the reasoning which led to hypothesis *H3*. These findings, regarding effects of service quality dimensions on satisfaction, acknowledge that even healthcare-adapted ServQual dimensions are not stable over different services and contexts [59]. The other findings confirm evidence of Hänninen et al. [54] and Parchman et al. [61] regarding the effects of diabetes care quality on service satisfaction. As a final remark we note that methods and evidence based interventions exist to improve the performance regarding the service quality dimensions responsiveness, tangibles, and caring [24].

From differences in operations to differences in outcomes

To identify notable differences in operations and to form hypotheses with regard to effects on outcomes we consider service, resources, and costs. A full description of operations in the case instances are given in the additional file [27]. Among the many operations variables to consider and possible hypotheses to explore we have again limited ourselves due to data quality issues and current scientific understanding. The analysis therefore focuses on follow up visits, access as well as service use and costs.

Table 4-9 Hierarchical regression analysis of service satisfaction [a]

Step	Variables	β						
		Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
1	Age	.03	.02	.02	-.01	-.01	.01	.01
	Gender [b]	2.61	2.41	2.84	3.45**	3.43**	3.44**	3.28**
	Education [c]	4.83	3.93**	1.31	.59	.50	.20	.17
	Time since diagnosis	.00	.00	.03	-.02	-.03	-.04	-.04
	Demand segment 2	-.24	-.29	-2.02	.07	.25	.55	.62
	Demand segment 3 (reference)							
	Demand segment 4	-.38	-.46	-.19	-1.81	-2.03	-2.12	-2.12
2	Alcohol consumption [d]		1.40	-.64	-1.91	-1.81	-1.85	-1.75
	Smoking [e]		-2.77	-2.12	-2.31	-2.41	-2.27	-2.38
	Physical activity		.15	.18	.05	.04	.02	.02
	HbA1CKnown [f]		3.00	4.98**	1.96	1.85	1.66	1.62
3	Model 1, GP/internist			-9.35**	-2.74	-3.48	-3.35	-2.07
	Model 2, GP/family doctor			-3.95*	-5.05**	-5.60**	-5.12**	-3.26
	Model 3, GP/nurse			6.68**	3.83**	3.75**	3.03*	3.22*
4	Tangibles				2.89**	2.94**	2.65**	2.57**
	Timeliness				1.72**	1.69*	1.68*	1.67*
	Responsiveness				2.98**	3.00**	2.60	2.60**
	Empathy				-2.21**	-2.14**	-1.59	-1.61*
	Caring				3.25**	3.20**	2.94**	2.96
	Communication				1.63*	1.52*	1.25	1.26
5	Number of visits					.52	.25	.21
6	Comprehensiveness						2.68**	2.60**
7	Travelling distance(km)							-.03
	Travelling time (minutes)							.12
	Waiting time in office (minutes)							-.07*

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Table 4-9 Hierarchical regression analysis of service satisfaction [a] (continued)

Step	Variables	β Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Statistics for cases without missing values								
	ΔR^2		.01	.05	.34	.00	.01	.01
	R^2	.02	.03	.08	.42	.42	.44	.44
	Δf	2.70	1.60	11.77	66.05	.19	15.07	2.49
	df1	6	4	3	6	1	1	3
	df2	677	673	670	664	663	662	659
	P value of Δf	.013	.172	.000	.000	.662	.000	.059
Statistics for data with missing values imputed								
	ΔR^2	0.01[✝]	0.00- 0.01	0.05- 0.06	0.33-0.34	0.00[✝]	0.01 - 0.02	0.00 - 0.01
	R^2	0.01[✝]	0.01- 0.02	0.06-.42	0.40- 0.42	0.40 - 0.42	0.41 - 0.43	0.42 - 0.44
	Δf	19.7- 2.65	0.093- 2.91	21.2-26.13	117.08- 126.00	2.61 - 6.29	27.01- 34.59	2.57 - 3.88
	df1	6	4	3	6	1	1	3
	df2	1452	1448	1445	1439	1438	1437	1434
	P value of Δf	.015 -.067	0.021- 0.444	0.000[✝]	0.000[✝]	.012 - .000	0.000[✝]	0.009- 0.053

[a] Service satisfaction measured on a scale ranging from 0 to 100. Unstandardized coefficients, $*p<.05$; $**p<.01$.
[b] 0=female, 1= male. [c] 0= minimum school leaving age, 1= more than minimum school leaving age.
[d] 0= No alcohol consumption, 1= alcohol consumption. [e] 0= Non-smoker and former smoker, 1= smoker.
[f] 0= HbA1c not known, 1= HbA1c known. [✝] Minimum and maximum values are equal.

In Table 4-8 we observe that there are differences in the number of follow-up visits between regions. Based on expert assessment we hypothesize a relationship between number of follow-up visits and satisfaction with services. We therefore hypothesize that:

H4: Higher number of follow up visits is positively associated with satisfaction with services.

Follow-up visits typically address a variety of diabetes issues and checks including the examination of blood glucose, blood pressure, cholesterol, eye, and feet problems. We define the degree to which diabetes issues and questions are thoroughly addressed between providers and patients as the comprehensiveness of the follow up visit. There are statistically significant differences between regions on comprehensiveness of follow up visits (Table 4-8). We therefore hypothesize that the comprehensiveness of the follow–up visits is associated with outcomes:

H5: Greater comprehensiveness of follow-up visits is positively associated with EQ-5D utility.

Furthermore, we hypothesize that comprehensiveness of follow-up visits augments patient experiences of receiving health services.

H6: Greater comprehensiveness of follow-up visits is positively associated with satisfaction with services.

Aspects of access to services measured by waiting times and distance and time to travel from patient home to provider location are given in Table 4-10. The access to services in Herakleion differs greatly with the access in for instance NWN & DWO. Differences in the access are tested using one way ANOVA for statistical significance.

There exists evidence that poor access to services is associated with worse health outcomes in older adults with diabetes [62, 63]. Based on this evidence and the analysts' assessment we hypothesize a direct relationship between access and EQ-5D:

H7: Waiting time in the provider location, travel distance to the provider location, and travelling time to provider location is negatively associated with EQ-5D utility.

Furthermore, evidence of Narayan et al. [64] and Joy et al. [65] indicates that access is a determinant of satisfaction with services. Bearing this in mind, we hypothesize that:

H8: Waiting time in the provider office/ clinic, travel distance to the provider office/ clinic, and travelling time to provider office/clinic is negatively associated with satisfaction with services.

The differences in average service use per region as presented in Table 4-11 are notable. The average use per year is calculated by average frequency of services per patient per year multiplied by time spent (in hours) to provide the services (see case instance descriptions in the additional file [27]). Average hours of care per patient are defined as service use by a diabetes patient and calculated as a weighted average over the demand segments per region. The data are extracted from provider information systems and patient records, complemented with interviews of providers.

Table 4-10 Perceived access to service

	Keski-Suomi	Bamberg	Herakleion	NWN &DWO	Valencia	Tower Hamlets	Total	Welch F[1]	Df1	Df2
Distance (km) (Statistics for cases without missing values)										
Mean	-	5.24	15.37	1.9	1.35	0.59	4.77	114.61*	5	454.02
Std. Error	0.59	0.32	1.47	0.1	0.11	0.05	0.25			
SD	7.51	5.14	19.02	1.9	1.11	0.81	9.05			
95% CI	6.98	4.62	12.47	1.71	1.13	0.49	4.28			
	9.32	5.87	18.28	2.1	1.57	0.69	5.26			
N	161	263	167	360	100	254	1305			
Distance (km) (Statistics for data with missing values imputed)										
Mean	8.76	5.50	16.19	2.09	1.48	1.68	5.18	42.43 -	5	454.02 -
Std. Error	0.76	0.46	1.54	0.31	0.69	0.33	0.29	53.26*		56.69
SD	9.82-10.22	6.19-6.63	20.19-20.33	5.67-5.84	3.03-3.84	4.75-5.27	10.36 - 10.51			
95% CI	7.15-7.51	4.53-4.98	12.82-13.53	1.42-1.62	0.35-1.42	0.99-1.33	4.5-4.71			
	10.07-10.38	5.98-6.53	18.82-19.5	2.57-2.79	1.48-2.81	2.07-2.4	5.56-5.79			
N	183	282	179	387	115	313	1459			
Travelling time (minutes) (Statistics for cases without missing values)										
Mean	15.72	13.21	27.46	8.12	13.24	14.39	14.22	62.09*	5	451.9
Std. Error	0.76	0.57	1.59	0.28	0.85	0.52	0.33			
SD	9.82	9.2	20.75	5.35	8.52	8.7	12.05			
95% Confidence	14.21	12.08	24.32	7.56	11.56	13.35	13.57			
	17.22	14.34	30.6	8.68	14.92	15.42	14.86			
N	165	256	170	359	101	275	1326			
Travelling time (minutes) (Statistics for data with missing values imputed)										
Mean	15.81	13.22	27.59	8.12	13.14	14.3	14.18	53.00-	5	514.64-

Table 4-10 Perceived access to service (continued)

	Keski-Suomi	Bamberg	Herakleion	NWN &DWO	Valencia	Tower Hamlets	Total	Welch F [1]	Df1	Df2
Std. Error	0.74	0.65	1.55	0.36	0.84	0.6	0.34	59.93*		16.78
SD	9.71-9.94	9.13-9.57	20.49-20.8	6.37-7.11	8.54-8.8	8.59-9.11	12.07-12.25			
95% Confidence	14.23-14.53	11.64-12.43	24.39-24.8	7.34-7.58	11.29-11.87	12.82-13.56	13.41-13.66			
	17.08-17.43	13.84-14.67	30.44-30.94	8.64-8.95	14.45-15.06	14.85-15.52	14.65-14.91			
N	183	282	179	387	115	313	1459			
Waiting time in office (minutes) (Statistics for cases without missing values)										
Mean	12.96	41.18	52.01	12.19	37.21	17.55	26.25	116.47*	5	472.4
Std. Error	0.64	1.62	2.78	0.5	2.24	0.62	0.69			
SD	8.03	26.55	36.28	9.48	23.18	10.39	25.12			
95% Confidence	11.7	38	46.52	11.21	32.77	16.33	24.91			
	14.21	44.37	57.5	13.18	41.66	18.77	27.6			
N	159	269	170	356	107	281	1342			
Waiting time in office (minutes) (Statistics for data with missing values imputed)										
Mean	12.75	41.28	51.75	12.21	37.26	17.87	25.94	115.99-25.51*	5	512.93 - 12.93
Std. Error	1.04	1.61	2.73	0.6	2.22	0.79	0.68			
SD	9.79-10.8	26.19-26.56	35.49-35.96	10.34-1.32	22.59-23.17	11.41-12.92	24.83-25.24			
95% Confidence	10.42-12.08	37.93-38.66	45.66-46.93	10.79 - 11.33	32.34-33.55	15.97-17.03	24.43 - 24.78			
	13.32-15.23	44.07-44.89	56.27-57.51	13-13.59	40.89-41.94	18.84-19.61	27.02-27.37			
N	183	282	179	387	115	313	1459			

Note: *p<.001, [1] Welch F test is reported as differences in variance between regions are significant. ✝ Minimum and maximum values are equal.

In general, one might expect that extra hours of service provisioning result in better outcomes, as we have assumed when formulating hypotheses 2 and 5. Table 4-11 displays that the average service use is the highest in Herakleion and the lowest in NWN & DWO. This suggests that another mechanism has the upper hand: worse outcomes lead to higher service use. The latter is confirmed by evidence [66] that well balanced HbA1c levels are associated with a reduction in service use, as well as the aforementioned findings of Shalev et al. [58]. We therefore hypothesize as follows:

H9: Lower use of services is associated with higher EQ-5D and a higher percentage of patients with a balanced HbA1c.

Table 4-11 Service use and costs

	Keski-Suomi	Herakle-ion	NWN & DWO	Valencia	Tower Hamlets
Length of stay (LoS)					
LoS in DS2 [1]	5	2	3	5	3
LoS in DS3	13	9	10	10	10
LoS in DS4	7.7	14	10	19	10
Total length of time as a diabetes patient	25.7	25	23	34	23
Service use [2]					
Diagnosis service (S2)	1.54	0.77	6.67	1.07	6.17
Life style service (S3)	1.27	1.11	1.12	0.56	2.09
Oral medication service (S4)	2.13	3.48	1.45	2.44	1.69
Insulin stabilization services (S5)	6.11	4.92	5.04	4.31	2.09
Insulin injection services (S6)	3.24	4.05	2.37	2.90	2.09
Average service use per patient	2.4	3.6	2.2	2.5	3.1
Costs					
Diagnosis (S2)	81	39	261	51	243
Life style services (S3)	78	140	48	26	74
Oral medication service (S4)	438	648	395	201	447
Insulin stabilization services (S5)	1788	1343	569	837	1017
Insulin injection services (S6)	1306	1245	1513	1139	1577
Average costs per patient per year	646	942	804	691	872

[1] The first year of stay in this segment is considered as the 'diagnosis year'.

[2] For all services, expressed in time units.

The analysts identified notable differences in service costs between regions (Table 4-11). Service costs are calculated as service use multiplied by unit costs. We use average costs adjusted by the purchasing power parity (PPP) for the year 2012 [67] for comparison purpose, which are costs per patient regardless of demand segment. It is worth noting that these are annual costs per T2D patient in primary care. Extra costs apply in DS5 and DS6 when secondary care is involved, which falls outside the scope of the demarcation used for the Managed Outcomes project. The differences in costs are derived from differences in the use of services and in the unit cost. This has been also reported in a study by Grieve et al. [66]. Following the reasoning of *H8*, we hypothesize that:

H10: Lower cost of services is associated with higher EQ-5D levels and a higher percentage of patients with a balanced HbA1c.

The association between follow up visits and outcomes

Having controlled for demand, behaviour and resource models, step 5 in Table 4-6 and Table 4-9 analyses hypothesis *H4*. This analysis shows that including the number of follow-up visits does not improve the explained variance in satisfaction with services so therefore we reject *H4*. Senic et al. [60] also found a non-significant relationship between the number of follow-up visits and satisfaction with services.

However, despite the expert arguments on positive effects of comprehensiveness on EQ-5D (*H5*), the analysis in step 5 in both Table 4-5 and Table 4-7 shows a non-significant association between comprehensiveness and the outcome and so we therefore reject hypothesis *H5*. Both step 5 models explain 24% (analysis without cases with missing values) and 21% (analysis with missing values imputed) of variance in EQ-5D.

The analysis in step 6 of both Table 4-6 and Table 4-9 shows that the comprehensiveness of follow-up visits is positively associated with satisfaction with services. This association is significant in both tables (resp. $\beta=2.7$, $p<.01$) and therefore *H6* is rejected. Now the explained variance slightly increases in a significant manner to reach 44%.

Increasing satisfaction through an increase in the comprehensiveness of services, rather than frequency of visits, might be related to convenience for users. Frequent visits require more effort in making appointments, travelling time, waiting time, and costs. Instead of frequent follow-up visits, users may prefer to have a comprehensive consultation as it covers various reviews of health status at the same time and therefore users are more satisfied.

The association between access and outcomes

Multiple regression models are shown in Table 4-5 and Table 4-7 which test hypothesis *H7*, while controlling for the earlier established associations. The regression models in step 6 Table 4-5 and Table 4-7 significantly increase the explained variance in EQ-5D utility. Therefore, this analysis proves the hypothesis *H7* that access and EQ-5D are positively associated. Travel time and waiting time are significantly and negatively associated with EQ-5D whereas distance is not (the effect on explained utility is small (both 0.001). However, these associations appear worthy of further exploration. Do unhealthier populations give rise to longer queues and waiting times and/or do longer waiting times lead to hurried and less adequate health service provision? Travel distance was not found to be significantly associated with EQ-5D utility.

The regression models in step 7 in Table 4-6 and Table 4-9 test *H8* regarding relationships between differences in access and differences in satisfaction with services. This analysis proves a significant negative association between waiting time and service satisfaction. The hypotheses regarding associations between service satisfaction and travel distance and travel time is rejected. These findings therefore partially support the evidence of Narayan et al. [64] and Joy et al. [65]. Total explained variance of both models now amounts to 45%. A study by Vinagre et al. [59] explains for 61% of variance in satisfaction with health services but without control for demographic characteristics and including non-operational variables.

Relationships between service use and health outcomes

The analysis of the relationships between service use and outcomes as formulated in hypothesis *H9* cannot rely on the same regression methods used above as data are from regional network instances and not from patient instances. In addition there are only 5 networks to be considered (there are no data available for Bamberg) so the small sample size limits the application of statistical methods. We therefore visually consider the hours of care in relation to the proportions of patients whose HbA1c is below the threshold value (HbA1c < 53 mmol/mol) [24]. Figure 4-4 shows the relationship between service use and HbA1c and Figure 4-5 shows relationships between service use and average value of EQ-5D utility.

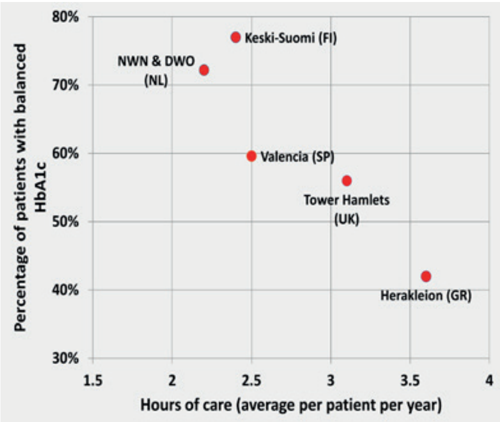


Figure 4-4 Relationships between effective control of HbA1c and total hours of care

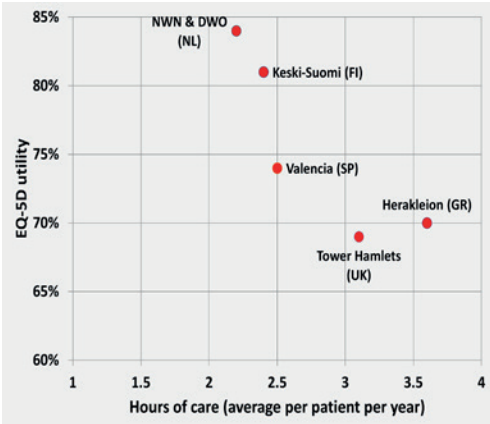


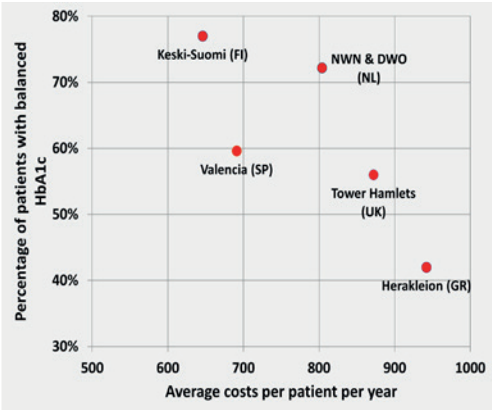
Figure 4-5 Relationships between mean EQ-5D utility score and total hours of care

Without claiming any scientific rigor, analysis of both Figure 4-4 and Figure 4-5 seems to confirm a negative relationships between service use and the outcomes as hypothesized in *H9* on the basis of scientific evidence. Note, however, that the presented data are cross-sectional and not longitudinal, and therefore sheds little light on causality.

Relationships between costs and health outcomes

The relationships between costs and outcomes (hypothesis *H10*), are shown in Figure 4-6 and Figure 4-7 by cost to the proportion of patient with balanced HbA1c levels and the average value of EQ-5D respectively.

Both analyses appear to support the hypothesis of negative relationships between costs and outcomes. In fact, Figure 4-6 shows that Keski-Suomi has the lowest annual costs and the highest percentage of patients with a controlled HbA1c level. In Figure 4-6 however, we observe that NWN&DWO has higher costs than Keski-Suomi yet also a higher average EQ-5D. On the other hand, the other regions have higher average costs and lower average EQ-5D utility.



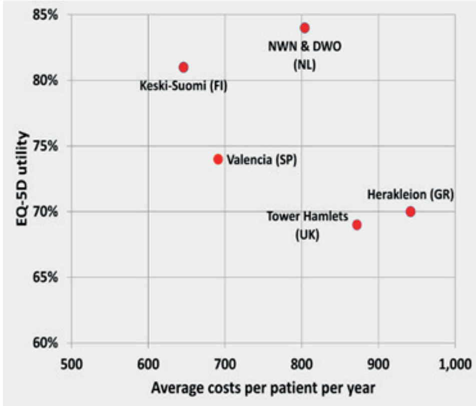


Figure 4-6 Relationships between costs and proportion of balanced patients (HbA1c<53 mmol/mol)

Figure 4-7 Relationships between average costs per patient per year (PPP for 2011) and EQ-5D utility

Discussion

The purpose of this study is to advance understanding of the relationships between operations and outcomes of diabetes provider networks along the framework presented in Mahdavi et al.[24]. It forms one study among several conducted in the Managed Outcomes project to advance insight in how health services can advance health outcomes through taking an operations management perspective.

Regarding outcomes, the study has focused on HbA1c management, Quality of Life, and service satisfaction. The presented models we have presented here have been able to explain 22% of the variation in EQ-5D scores and 45% of service satisfaction. Although 22% may be considered to be a modest achievement, we note that the analysed operational variables (including health behaviour), explain as much of the variance as the demographic variables modelled. Regarding the service satisfaction, the service operations and behavioural variables explain up to 44% of 45% variation.

Further improvement of explained variance is certainly possible. Our analysis has been limited by the quality of some of the collected data which had to be excluded from the analyses. This was particularly the case for co-morbid conditions and the transitions between health states. Further research into the associations between comorbidities, service provisioning and quality of life would appear to be a natural direction for further research. Another direction for improvement is in the modelling of health services. In the models presented we have considered the health service standards and modelled services at the network level, as opposed to the patient level. It might be expected that further refinement of the services modelling at the health service user level would improve their predictive power.

We have not collected clinical data at the patient level, and have therefore not been able to present any analysis regarding the relationships between the service operations and the clinical health outcomes. It might be expected that the clinical outcomes mediate the relationships between service operations and quality of life, and further exploration of the relationships between health service operations and clinical outcomes and between clinical outcomes and quality of life are also areas worthy of further exploration.

This paper, by and large, disregards results which consider demand segments in depth or transition probabilities. It is reasonable to expect that the relationships analysed might differ by demand segment and so considering the demand segments separately may further improve the understanding of the relationship between outcomes and operations and other model entities.

Although it is tempting to reason that operations are determinants of outcomes, our results indicate that the direction of effects from structures to processes to outcomes as established by Donabedian is too simplistic. We have established that higher costs and service use are associated with worse health outcomes. This strongly suggests a mechanism in which patients in poorer health make heavier use of health services, and so implying causality from outcomes to operations. Our results indicate some suggestions how regions with worse outcomes might improve outcomes and reduce costs. Regarding the quality of life, it appears to be worthwhile to introduce or increase a role for nurses in the service provisioning. Likewise, the co-creation by patients is important, both through health behaviour, as well as in service behaviour (e.g. by them knowing their HbA1c level and understanding the importance of the need to control it).

Conclusions

The models, which capture service operations, explain a noticeable part of variance in the outcomes in particular service satisfaction. Given these promising results, and their universal applicability, they form a sound basis to advance the evidence base and understanding of the operations management of primary care networks for type 2 diabetes.

By providing a detailed operational model, which has been successfully applied in six different countries, we have shown it is possible to capture essential features of the relationships between operations and outcomes for T2D networks and reported detailed evidence based on the framework presented in Mahdavi et al.[24]. The results demonstrate the appropriateness of the model and invite future application. This could include more detailed modelling of T2D networks; an extension of the T2D-specific models to enhance the current model; and application of the generic modelling framework to other diseases groups or medical conditions. Further work on applying the model in this way will be reported through subsequent publications from the Managed Outcomes project.

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Chapter 5

Modelling and Evaluation of Stroke Service Provider Networks

This chapter is based on:

Mahdavi, M., Vissers, J., van de Klundert, J., Elkhuizen S., Konerding, U., Faubel, R., Bowen, T., Torkki, P., Pavi, E. Modelling and evaluation of stroke service provider networks. This chapter is presented at 40th conference of Operations Research Applied to Health Services (ORAHS), Lisbon 2014.

This paper is in progress for submission.
Submission is conditional on the outcome of review of the papers in chapters 3 and 4.

Abstract

Background: Stroke is one of the leading causes of death and morbidity worldwide. This research aims to analyse the relationships between stroke service operations and outcomes in regional stroke service provider networks.

Methods: The study method builds on the modelling and analysis methodology presented in Mahdavi et al. (2014a). Using this methodology we derived first a stroke-specific model to describe demand, services & structure, behaviour and outcomes. Subsequently, service operations and outcomes of secondary care networks for stroke care in six European countries are described. Finally, using a number of hierarchical and logistic regression models, we analysed the relationships between (differences in) operations and (differences in) outcomes.

Results: Following the journey of the user through the system we explored effects that emergency response, diagnosis, admission to stroke care unit and rehabilitation have on outcomes at patient level and network level. At both levels, emergency response and diagnosis are found to consistently affect health and service outcomes in a positive manner. With regard to the effects of a higher percentage of admissions directly to stroke care unit results are contradictory at the different analysis levels. While at patient level, logistic regression models show non-significant relationships with health state, at network level the relationships suggest positive effects on health state. The models and analyses show that only a limited part of the variance in health outcomes can be explained by operations. However, satisfaction with services can be captured well with operations. Tangibles and responsiveness appear important determinants.

Discussion and conclusions: Our findings indicate that existing evidence falls short of explaining the relationships between operations and outcomes of stroke provider networks. Through the developed operational models and subsequent analysis, we provide multiple case study results and provide a basis for advancing evidence on the relationship between outcomes and operations in stroke service provider networks.

Keywords: Stroke, Provider networks, Operations Management, Outcomes

Background

Stroke is one of the leading causes of death and long-term disability of adults in the world. With 25% of mortality rate within one month and 50% within one year stroke is one of the most fatal diseases worldwide [1]. The burden of stroke and its economic impact on families and health systems is increasing globally because of aging of population and new escalating trends of co-morbid conditions [2]. It is estimated that 16 million suffered from a first-ever stroke in 2005, while 62 million were living with consequences of stroke. From 1970 to 2008, mortality of stroke decreased by 42% in developed countries; however, the incidence of stroke decreases in a lower rate than mortality, which in turn leads to an increase in the prevalence of stroke and thus increased demands on health care and social care systems [2]. Stroke accounts for 3–4% of the total healthcare expenditures globally [3].

Stroke is caused by disrupted supply of blood to the brain which may lead to permanent brain damage. As an emergency condition every second counts in diagnosis and treatment of stroke patients. All stroke patients should be admitted to a facility with a stroke care unit or at least a multidisciplinary team of stroke professionals, preferably within 6 hours from the onset of symptoms [4]. This limited time window indicates that fast track emergency response and acute treatment and therefore effective stroke service operations management could be a matter of life and death for stroke victims [5]. The importance of stroke management is represented in goals and aims set for the future by formal declarations. The Helsingborg Declaration 2006 on European Stroke Strategies for instance has set goals on five areas of "organization of stroke services, management of acute stroke, prevention, rehabilitation, evaluation of stroke outcome and quality assessment to be achieved by 2015 [6].

5

Stroke care encompasses a spectrum of services including community education, emergency dispatch, acute and sub-acute treatment, and rehabilitation [7]. These services are typically fragmented across healthcare providers (departments or institutions) across regions. Provider networks are established to remedy issues related to the fragmentation [8]. Provider networks may be formed by means of explicitly defined collaboration [9] or implicitly as collections of providers jointly visited by (a population of) stroke patients [10]. Stroke provider networks have become increasingly popular during the last decades to improve stroke care in geographical regions [11]. In such networks health and well-being of patients rely on service operations of the provider network as a whole. By stroke service operations we mean a set of services that use or consume resources to improve stroke patient outcomes. Analysis (evaluation) of relationships between operations and outcomes of provider networks is crucial in developing an evidence base for effective provisioning of stroke services for a population of regional networks [12]. Given the importance of an evidence base for the management of stroke in regional systems of stroke care, our research addresses the relationships between the operations of health service provider networks for stroke care and the outcomes obtained.

Of the vast amount of literature available considering the organisation of stroke service operations including planning, process modelling, efficiency, costs, utilization, access, and performance improvement [1], we briefly highlight some recent contributions. Bayer et al. describe a model to map the care flow and to support local care planning [13]. Murphy et al. investigate process time to administer the tissue plasminogen activator (tPA), emergency response performance, and role of nurses [14]. Na et al. use modelling approaches such as Monte Carlo simulation and Markov Decision Process to reach a trade-off between resource waste and patient wait and to develop a sound cancellation policy [15]. Ozcan et al. analyse technical efficiency of stroke care in United States' hospitals [16]. Moynihan et al. studied access to thrombolysis and evaluated different strategies to improve the rate of patients who undergo this treatment [17].

Since the pioneering work of Donabedian [18] on evaluation of healthcare and more recently evidence based health service management [19], stroke care research has considered linkages between service processes and structure on one hand, and outcome (service outcomes or health outcomes), on the other hand. The recent systematic review by Parker et al. [20] however reports little evidence for relationships between stroke service and outcomes. Even for service operations with proven effectiveness through controlled trials, it has been surprisingly difficult to demonstrate that these processes influence patient outcomes [21]. While a number of studies report positive associations between operations and outcomes [22, 23], other studies mostly report weak or insignificant associations [24, 25]. Therefore as Reeves et al. [26] and more recently Parker et al. [20] conclude that more research is required to better understand relationships between operations management of stroke services and patient outcomes.

Mahdavi et al. conclude that, more generally, very little evidence exists between operational models and outcomes for health service provider networks [27]. In a subsequent study a generic framework was developed to model and evaluate such provider networks [28] and to develop evidence for the relationships between operations and outcomes. This study applies this framework as a generic service operational model to regional stroke provider networks as called for by Monks et al [29]. Henceforth, we simply refer to such networks by 'stroke network'. The results are based on a multiple case study which includes six stroke networks in Europe, as studied in the FP7 project Managed Outcomes.

The outline of this paper is as follows. In section Methods we present the modelling and evaluation methodology for evidence based health service operations in stroke care. In section Results and discussion the results of the study are presented and discussed. In the last section, conclusions and recommendation for future research are presented.

Methods

This research is part of a series of multiple case studies which build on the framework for modelling and evaluation methodology presented in Mahdavi et al. [28], and applied before to primary care networks for Diabetes in Mahdavi et al. [30]. The framework enables to develop generally applicable and replicable models for health service operations that can be applied to specific disease settings. The framework offers two model levels of which the first level is a generic level to specify generic health service operations entities and the second level is a disease-specific level to add entities to the generic model or to redefine entities of the generic model. The disease specific models capture two types of instances, namely network instances (to enable modelling of the networks) and health service user instances (to enable modelling of health service users, patients). We refer to Mahdavi et al. [28] for a detailed description of the framework, and elaborate on the application to stroke networks below.

The stroke model inherits the five core entities for modelling of health service operations from the generic model: demand, services, structure, behaviour, and outcome (See Figure 5-1). The generic model captures current scientific understanding that outcomes are not solely determined by service provisioning but that health behaviour and health conditions (demand) interact with the service provisioning processes and structures and jointly affect outcomes.

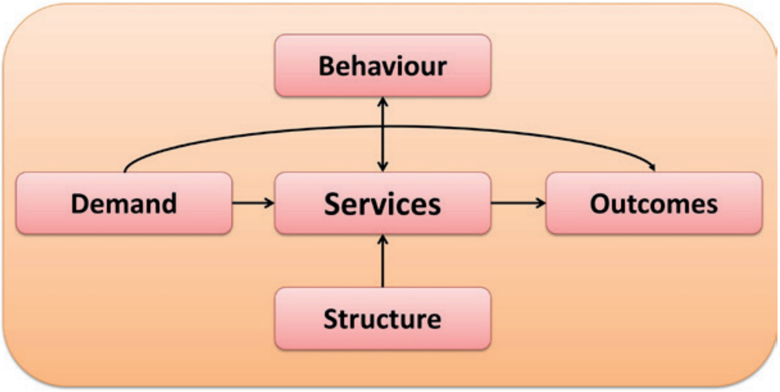

Figure 5-1 Relationships between demand, services, structure, behaviour and outcomes

Table 3-1 provides information on the (generic) components of the 5 core entities of the operational model in Figure 5-1.

Stroke Model

The disease specific model for stroke, henceforth called stroke model specifies the five generic entities demand, services, structure, behaviour, and outcome for stroke provider networks. A stroke network serves a population of stroke patients who live in a geographical region. The details of the stroke model are provided in the paper appendix. We also present five case instance descriptions in the paper appendix and with more details in the online additional file at the ResearchGate.

The stroke model distinguishes segments of demand for stroke care, where the service users in a same segment share a common health state and subsequently the same services. The majority of demand for stroke care is generated by three main cerebrovascular events, which lead to different health service use: TIA (Transient Ischemic attack), cerebral infarction (ischemic stroke), and haemorrhage (primary or subarachnoid) [31] (haemorrhagic stroke). The term TIA is used when the signs of stroke are present but disappear within 24 hours. Cerebral infarction, also known as ischaemic stroke, occurs because of a blood clot or plaque which has migrated to the brain from elsewhere in the body. Haemorrhagic stroke occurs because of breaks or bursts in an artery, which lead to bleeding. Cerebral infarction accounts for 80% of stroke cases, excluding TIA cases [32].

5

Table 5-1 illustrates the demand specification used for the stroke project as part of Managed Outcomes.

Table 5-1 Specification of demand for stroke (illustrated for the Managed Outcomes project)

Generic subcomponents of demand	Stroke specified demand
Demand location	Regions, urban areas, rural areas.
Demand segments	High risk individuals (DS1)
	Transient Ischemic attack (DS2)
	Haemorrhagic stroke (DS3)
	Ischemic stroke (DS4)
	DS4a: Patient with ischemic stroke attended in stroke unit*
	DS4b: Patients diagnosed with ischemic stroke not attended in stroke unit
Stroke patients characteristics	Age, gender, education, ethnicity, number of previous stroke, type of stroke, and time since last stroke.

* Criteria to be treated in stroke unit: ischemic stroke less than 24 hours evolution or Ischemic stroke in progression or TIA repetition. Excluding: patients with Barthel < 85, Modified Rankin Scale > 2, disabilities, short life expectancy, and dementia.

As differences in demand characteristics lead to differences in outcomes [33], the model subsequently describes the demand characteristics for a population of stroke per a segment or per region as a whole. These characteristics include age, gender, education, number of previous strokes, type of stroke, and time since last stroke [20].

As ischaemic stroke accounts for 80% of non transient strokes, we further focus on ischaemic stroke, and hence on segment DS4. We now consider in turn the four other generic components: services, structure, behaviour, and outcomes. Services are defined as ordered sets of service elements, the atomic process units [34]. For stroke networks, we define service elements using the best practice recommendations presented by Adams [35]. A complete list of service elements with definition is provided in the Stroke model appendix. Stroke networks may deliver three different services to the service users in DS4: diagnosis, acute treatment, and rehabilitation (Table 5-2). A sequence of these services constitutes a service user journey.

Next we turn to the model entity structure which addresses the service provision points (SPPs) and resources for service provisioning [28]. Service providers represent the health service organizations involved. In some networks, all services in provider networks are centralized in a single SPP e.g. a regional hospital, whereas other networks have a hub-and-spoke architecture. [17]. Furthermore, two stroke care practice designs can be distinguished: stroke care unit based practices and triage-based practices. In a stroke unit based practice all stroke patients are admitted to the stroke unit for treatment in the initial stabilising phase. A stroke unit is a well-equipped centre with specialized personnel, programs, expertise, and infrastructure to admit stroke patients [36]. To accelerate recovery and improve outcomes, rehabilitation starts immediately after admission to the stroke care unit [37]. In a triage-based practice design only complicated stroke patients are admitted to a stroke unit, and the less severe or the very severe cases are admitted to a medical ward.

Table 5-2 Service and structure for ischemic stroke

Service/service journey	Service elements		Resource
Diagnosis (S1)	Symptom identification Ambulance Primary care visit ED care Neurological exploration Basic diagnostic test ED Perfusion CT Angio CT	Image diagnostic test CT–scan1 Image diagnostic test MRI 2 Basic diagnostic test ward Detailed neurological exploration Additional image diagnostic test Cardiologic test Other tests: EEG Other tests: arteriography	Ambulance team, bed in emergency department, etc.
Ischemic treatment (S2)	Anti-aggregation Anti–coagulation Thrombolysis Intra–arterial stroke therapy Carotid angioplasty Endartectomy	Stroke unit care Neurology ward care Internal Medicine / Medical ward Ward for patients waiting for follow–up Intensive care	MRI, CT, bed and nursing staff in stroke unit, bed and nursing staff in neurology ward etc.
Specialist rehabilitation (S3)	Physiotherapy bedside Speech therapy Social worker Dietician Occupational therapy	Activity support RHB physician exploration Rehabilitation Discharge	Physiotherapist, speech therapist, occupational therapist, etc.

5

Table 5-3 Health behaviour and outcomes for stroke

Generic components		Description of stroke model
Behaviour	Non-service related behaviour	Smoking, Alcohol consumption
	Service co–creational behaviour	Adherence to specific medication, adherence to a special diet, adherence to a specific therapy regime, adherence to specific physical exercises
Outcome	Health outcomes	Mortality within hospital, mortality within one month, mortality within three month, mortality within one year.
		EQ-5D health related quality of life in relation to mobility, self-care, usual activity, pain/discomfort, anxiety/depression Satisfaction with health status
		Health status influenced by stroke (Modified Rankin Scale (mRS) Short form of the Stroke and Aphasia Quality of Life Scale (SAQOL-39) Adaptation of life (AoL) to impairment caused by stroke
	Service outcomes	Perception of service quality (SERVQUAL) Evaluation of service quality in comparison with best and worst imaginable services Satisfaction with service

The resources requirements are specified per service element [38]. A sample of resources for stroke services is given in Table 5-2 and a complete list is given in the Stroke model online additional file. Costs are defined per resource capacity unit.

The stroke model specifies patient behaviour in the form of non-service related behaviour and service co-creational behaviour (Table 5-3). Non-service related behaviour describes life-style attributes such as smoking and alcohol consumption. The service co-creation regards therapy adherence [39].

Outcomes in the stroke model include service and health outcomes from both patient and provider perspectives [18]. Various health outcomes can be measured for stroke patients. A first health outcome is mortality (Table 5-3). Other measures are taken from the Stroke and Aphasia Quality of Life Scale-39 (SAQOL-39), the Modified Rankin scale (mRS), the EuroQol EQ-5D and visual analogue scale (VAS) of EQ-5D, and satisfaction with health [20]. SAQOL-39 measures the stroke specific health outcome which represents the health state directly influenced by having a stroke. Another health state measure, which may be directly related to stroke operations, is the Modified Rankin Scale [40]. The general health state measure, EQ-5D regards five dimensions of health: mobility, ability of performing self-care, ability of performing usual activities, pain/discomfort, and anxiety/depression [41].

Service outcomes describe the quality dimensions tangibles, timeliness, responsiveness, empathy, and communication [42]. Two further measures are the evaluation of the service in comparison with the best and the worst imaginable service, and the satisfaction with stroke services (see Table 5-3). Perception of stroke services regards also the perceived access to services. Access is measured by waiting times, distance to provider office and travelling time to provider office.

Case Instances

A case instance of provider networks is an instance of a stroke specific model that provides values for the components of the disease model description considered in a region [28]. In this research six instances of the stroke model (stroke networks) were studied in 2011. These instances reside in the regions Keski-Suomi (Finland), Erlangen (Germany), Athens (Greece), Tilburg (Netherlands), Valencia (Spain), and Brighton (UK). The study countries were selected in advance in the Managed Outcomes project and the study includes one region per country.

The Stroke model provides a comprehensive set of variables for analysis of stroke provider networks. We present and analyse the model components for which the collected data is of sufficient quality (See Table 5-4). Most of the data defining the stroke networks, i.e. the network instances, have been collected from interviewing and medical information systems. In each of the six regions the data were uniformly collected using a standardized spreadsheet format to instantiate (demand) services, and structure. The description of instances can be found in the online additional file. Health service user data have been collected through a survey which is described below.

Instruments and Data Collection

Most of the data on demand, behaviour, and outcomes was collected by surveying patients living in the regions of the provider networks (See the stroke model) using a questionnaire. The questionnaire addressed the demand characteristics age, gender, education, number of strokes, type of stroke, and time since last stroke. The questionnaire on general health behaviour contains questions regarding smoking (smoker or non-smoker) and alcohol consumption.

Table 5-4 Operations, behaviour and outcomes considered in analyses

Operations	Behaviour	Intermediate outcomes	Health state/quality of life
Frequency of services [1] Frequency of service elements per service [1] Duration of service [1] Duration of service elements per service[1] Resource type [1] Services use (frequency x duration) [1] Amount of service elements per service [1] Waiting time for emergency response [12] Waiting time until diagnosis [12] Door to needle time [1] Door to CT scan [1] Costs of service element, service journey, and service user journey [1] Service quality (ServQual dimensions) [2]	Smoking [2] Alcohol consump-tion [2]	Percentage of thrombolysis [2] Length of stay in hospital [12]	In-hospital mortality rate [2] mRS immediately after stroke [2] mRS at the time of survey [2] EQ-5D-utility according to Dolan at the time of survey [2] Adaptation of life to impairments caused by stroke [2] Service satisfaction [2]

[1] operational model, [2] Survey

Data for service quality are collected by a short form of the ServQual questionnaire proposed by [42]. The stroke survey on service outcomes also contained data on the perceived aspects of operations: waiting time for emergency response after the emergency call, length of time to establish diagnosis, length of hospital stay, waiting time to receive rehabilitation service, traveling time to, and distance from rehabilitation centre.

Among the outcome measures, mortality data was collected. We also used a modification of the Modified Rankin Scale (mRS) [40] to retrospectively measure health state at two points in time, one immediately after stroke (baseline health status) and another at time of survey (6-12 months after most recent stroke). Although the original mRS is meant to rate the health state by a different person than the patient, we modified this scale into a self-completion scale. All six categories on this scale were represented in all of the six study regions. Furthermore, the EuroQol instrument was used to measure perception and evaluation of general health conditions at the time of survey. The response options used were: no problems (score of 1), moderate problems (2), extreme problems (3). The five dimensions can be mapped onto a utility index which is anchored with 0 for death and 1 for perfect health. Satisfaction with services is measured with seven options from least satisfaction (score of 1) to extreme satisfaction (score of 7).

The original questionnaire was in English language which was culturally adapted [43]. This questionnaire was translated into the native languages of the non-English speaking regions. To reduce bias in translation two native speakers of the target language translated the questionnaire from the original language to the target language and then one native English speaker translated the questionnaire already translated by the two native speaker of the target language back to English. The questionnaires were approved by the ethics committees in the corresponding countries. Before sending to patients, all personal identifiers were removed or disguised so the person(s) are not identifiable and cannot be identified through the details of the responses. All participants received a letter with research information and an invitation to fill in the questionnaire.

Table 5-5 Surveys

	Finland	Germany	Greece	Netherlands	Spain	United Kingdom	
Regions	Keski–Suomi	Erlangen	Athens	Tilburg	Valencia	Brighton	Total
Investigated hospitals	1	1	1	2	1	1	7
Questionnaires distributed	600	366	126	625	306	346	2369
Questionnaires returned	190	126	65	224	101	120	826
Response rate (%)	31.7	34.4	51.6	35.8	33.0	34.7	34.9
Questionnaires meeting all requirements	160	110	52	210	72	94	698

Stroke patients were labelled through the hospitals participating in the study. Patients who were diagnosed as transient ischemic attack (TIA) and patients who died during their hospital stay were excluded from the final list of survey, which resulted in a sample total of 2369 patients. On behalf of the Managed Outcomes project, study hospitals sent the questionnaire by post to the patient address during 2010 and 2011. We received in total 826 questionnaires from patients, resulting in an overall response rate of 34.9%.

Analysis methods

This study purpose is to advance understanding of relationships between operations and outcomes of stroke provider networks. The analysis methods used in this paper is based on the approach propose by Mahdavi et al. [28]. The analysis is cross sectional, thus limiting the attribution of differences in outcomes to differences in operations. Nevertheless, the design allows to contribute to advancing evidence based operations management in health service provider networks by uniform and systematic assessment of relationships between operations and outcomes.

The analysis approach enables us to analyse relationships between (differences in) health service operations and (differences in) outcomes through two related basic steps:

A) Systematic exploration of notable differences in outcomes between the regional instances in relation to notable differences in operations. The relationships with operations which are hypothesized to explain for differences in outcomes are based on theory, scientific evidence, and expert opinion.

B) Systematic exploration of notable differences in operations and to consider the interrelationships with notable differences in outcomes. Relationships for exploration are proposed using theory, scientific evidence and expert opinion.

Whenever possible, notable difference refers to statistically significant difference. A list of operational components and outcomes for stroke case instances is given in Table 5-4.

The hypothesized relationships are investigated using statistical methods when feasible, in particular cumulative logit models and hierarchical regression models. The statistical analysis was conducted by the IBM SPSS statistical package version 20.

Results

This section present results on relationships between operations and outcomes in stroke provider networks in the Managed Outcomes project. As operational data for Erlangen was incomplete, analysis of operations is most of the time restricted to five case instances. The majority of data for outcomes and perceived operations were based on a total of 698 patients. The analysis follows the sequential “chain of stroke recovery and survival,” which addresses how key domains of stroke care, such as emergency response, acute and hyper acute treatment, secondary prevention, and rehabilitation, influence health outcomes. Subsequently, we form hypotheses regarding relationships between operations and health outcomes following this logic [8, 44].

From differences in outcomes to differences in operations

Outcomes for stroke services in the six regions are given in Figure 5-6. Data for outcomes, except mortality, are derived from the patient survey.

The differences in mortality between regions are not significant (p=0.063). As there are no patient level data on mortality, further statistical testing of operational causes on mortality is infeasible. However, as mortality is relatively rare in the regions, analysis at patient level is likely to suffer from insufficient statistical power anyway [45]. We therefore present a network level analysis of the relationship between the operational variable treatment in stroke care unit and mortality.

After control for age, gender, education, health status immediately after stroke, and previous stroke there were statistically significant differences between the regions regarding mRS at time of survey. Before control Brighton had the lowest health state (Figure 5-6). After control for demand, Valencia has the lowest health state (Table 5-7). To analyse differences between the regions in mRS at time of survey a cumulative logit model with control for demand characteristics was built (Table 5-7).

To explain for differences in health state between regions we rely on the analysis logic and the evidence stating that speed of pre-hospital emergency response [46] and direct admission to stroke care unit influence the health state [47, 48]. The larger the proportion of patients directly admitted to the stroke care unit, the better the health outcomes at population level. We therefore hypothesize that:

H1: A higher health state at the time of survey is positively associated with shorter emergency response and time to establish diagnosis.

H2: A higher health state at the time of survey is positively associated with the proportion of patients admitted to the stroke care unit.

Table 5-6 Outcomes of stroke services

Regions		Keski–Suomi (FI)	Erlangen (G)	Athens (GR)	Tilburg (NL)	Valencia (SP)	Brighton (UK)	Total	df1	df2	Welch F test
In-hospital mortality rate (per 1000 cases)		3	NA	4.6	5.6	8	13	NA			
Health state at time of survey [1]	Mean	2.36	2.48	2.77	2.46	2.61	2.91	2.55	5	299.7	2.61*
	SD	1.34	1.52	1.61	1.30	1.24	1.54	1.41			
	N	190	126	65	224	101	120	826			
Adaptation of life [2]	Mean	83,6	68,9	57,2	51,7	68	72,2	67,1	5	268.9	21.96**
	SD	23,1	36,8	39,9	38,5	36,9	33,4	36,3			
	N	174	115	59	204	96	108	756			
EQ–5D utility index [3]	Mean	0,72	0,69	0,64	0,73	0,64	0,65	0,69	5	288.7	3.32**
	SD	0,24	0,31	0,29	0,23	0,31	0,24	0,26			
	N	174	115	59	204	96	108	756			
Service satisfaction [2]	Mean	82	81,2	82,3	83,3	86,6	75,2	81,8	5	293.7	2.38*
	SD	24	23,6	22,8	25,5	21,2	28,2	24,7			
	N	162	119	63	215	97	117	773			

[1] This measure scored with 1 for the best health state and 6 the worst state.

[2] The scale is standardized with 0 for death and 1 for full health [45]

[3] These measures scored with 0 for worst possible and 100 for best possible value.

Table 5-7 Analysis of differences between regions in health state at the time of survey

Regions	Controlled		Included persons
	Odds ratio[a]	Ln(Odds ratio)[a]	
Keski–Suomi (FI)	0.846	-0.167	150
Erlangen (G)	1.236	0.212	105
Athens (GR)	1.476	0.389	51
Tilburg (NL)	0.772	-0.259	200
Valencia (SP)	1.950	0.668	69
Brighton (UK)	1.000	0.000	89

[a] Odds ratios refer to being in the worse of the two sides of any possible dichotomisation of the Modified Rankin Scale. Brighton serves as reference region. Higher numbers mean lower health state.

Now, we turn to perceived AoL. Analysis of variance (ANOVA) shows that there are significant differences in this outcome measure (Table 5-6). Subsequently, we controlled for differences between the regions using a cumulative logit model in Table 5-8.

Table 5-8 Analysis of difference between regions in adaptation of life to impairments

Regions	Mean	Values standardised with respect to Brighton		Persons included
		Uncontrolled	Controlled	
Keski–Suomi (FI)	83.45	6.942	6.357	145
Erlangen (G)	69.25	-7.256	-7.262	100
Athens (GR)	60.87	-15.636	-12.566	46
Tilburg (NL)	52.73	-23.772	-25.619	192
Valencia (SP)	66.30	-10.202	-6.173	69
Brighton (UK)	76.51	0.000	0.000	83

There are also significant differences between regions in AoL before and after control for demand and behaviour (Table 5-8). Before and after control, the value for Keski-Suomi is the highest and the value for Tilburg is the lowest. Rehabilitation helps patients to acquire new skills to cope with impairments caused by stroke [49]. Empirical evidence of Mackenzie et al. [50] supports a positive association between rehabilitation services and AoL. We therefore hypothesize that variance in rehabilitation services may explain for AoL:

H3: A higher adaptation of life is positively associated with total rehabilitation service time.

We also compare the regions with regard to EQ-5D utility. Without control for effects of demand and behaviour there are significant differences between regions. These variables include age, gender, education, health status immediately after stroke, and previous stroke. These differences disappear when we control for such variables by hierarchical regression models. Nevertheless, we note that after control for demand and behaviour Tilburg has the highest and Valencia the lowest values.

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Table 5-9 Hierarchical regression analysis of satisfaction with services

Step	Variables	β Step 1	Step 2	Step 3	Step 4	Step 5
1	Age	.05	.06	.05	.07	.10
	Gender [a]	-.03	-.03	-.03	-.01	.05
	Education [b]	.18*	.16	.16	.21*	.09
	Alcohol consumption [c]	-.07	-.07	-.08	-.08	-.06
	Smoking [d]	.06	.05	.05	.01	-.06
	Health state at the time of survey[e]	.31**	.30**	.29**	.30**	.15*
2	Design of stroke care [f]		.07	.07	.01	-.04
3	Time from call to medical help arrives			.03	.02	-.10
	Time from onset to diagnosis			-.10	-.04	.09
4	Advice on impact of stroke on life				.12	-.06
	Discussion advice				.16	.18
	Advice regarding risk factors				-.21	.02
	Discussion risk factors				.34*	.04
5	Tangibles					.18*
	Timeliness					.10
	Responsiveness					.29*
	Empathy					.12
	Caring					-.11
	Communication					.18
	ΔR^2		.00	.01	.16	.29
	R^2	.14	.14	.15	.30	.59
	F change	3.86**	.64	.55	7.78**	15.76**
	df1	6	1	2	4	6
	df2	147	146	144	140	134

[a] 0=female, 1= male. [b] 0= minimum school leaving age, 1= more than minimum school leaving age.
[c] 0= No alcohol consumption , 1=Alcohol consumption. [d] 0= Non-smoker and former smoker, 1= smoker.
[e] 0=State worse than "Symptoms, but able to carry out usual duties and activities after stroke", 1= State better than "Unable to perform all usual activities, but able to look after own affairs after stroke".
[f] 0= Triage-based design, 1= Stroke care unit-based design. *p<.05, **p<.01; (standardized coefficient, listwise, two-tailed).

Given the non-significant differences after control for the demand and behaviour we do not further analyse EQ-5D using statistical methods, although we present an analysis regarding relationships between this quality of life measure and costs at the network level for benchmarking purposes.

Next to mRS and adaptation of life we consider satisfaction with services. This outcome parameter in addition to being a service outcome is a predictor of the health state in stroke patients [51]. Hierarchical regression reveals differences in service satisfaction between regions, while controlling for demand and behaviour characteristics (See step 1 Table 5-9).

Based on a post-hoc analysis performed, significant differences in service satisfaction exist between Tilburg and Brighton (Table 5-6). Based on the analysis logic we hypothesize relationships between satisfaction with services and speed of response and diagnosis and treatment in a SCU:

H4: Shorter emergency response and shorter time to establish diagnosis are positively associated with satisfaction with services.

H5: A higher satisfaction with services is positively associated with the proportion of patients admitted to a stroke care unit.

In addition, we propose that counselling and discussing the impact of stroke and risk factors will augment service experiences based on Helkkula et al. [52]. Furthermore, according to Bowers et al. [42] who applied the theory of the Service Quality Gap model [53] on health services, patient perceptions of tangibles, responsiveness, timeliness, empathy, caring, and communication explain differences in service satisfaction. We therefore hypothesize that:

H6: There are positive relationships between giving advice and possibility to discuss issues (regarding impact of stroke on life and risk factors of stroke) and satisfaction with services.

H7: There are positive relationships between perceived operational aspects of service quality and satisfaction with services.

Below we test the proposed hypotheses. In the analyses, step 1 controls for demand and behaviour characteristics. Step 2 controls for effects of regions or stroke care design. In step 3 we test the hypothesized operational components.

The association between health state and speed of response and diagnosis

We test the hypothesized relationships between emergency response and time to diagnosis and health state at the time of survey using logistic regression models in Table 5-10.

Analysis in step 1 in Table 5-10 shows that age, education, and health state immediately after stroke are significantly associated with health state at the time of survey. Health directly after stroke has the largest effect (OR= 28.61, p<.001). The worse the health state directly after the stroke, the worse it is at the time of the survey. Older age has also essential adverse effects on recovery from stroke. Gender, alcohol consumption, and smoking do not have statistically significant effects on the health state. In step 2, region as a contextual variable is controlled for. In step 3 the inclusion of emergency response time and time to establish diagnosis into the analysis increases the explained variance in health state at time of survey. The improvement in the regression model is statistically significant. However, neither emergency response time nor time to establish diagnosis made a significant contribution to health state at time of survey. These findings don't confirm results by Lees et al [54] who find that every minute decrease in time from onset to treatment is associated with 1.8 extra days with healthy life. Notice also that health directly after stroke is the only demand variable which remains to be significantly associated with health at time of survey.

The association between health state and admission to stroke unit care

To test *H2* we use a two-dimension graph to represent data for the six network instances [28]. The graph relates the network instance outcome variable percentage of patients with mRS lower than category 3 to the network instance operational variable proportion of patients admitted to stroke care unit (Figure 5-2). Data for mRS is derived from the survey and data for proportion of admission to SCUs is derived from case instances.

The analysis in Figure 5-2 indicates a positive relationship between mRS < 3 and admission to SCUs: as the proportion of admission to stroke care unit increases, the proportion of patients with good health state increases. All regions with a 100% admission rate to SCU have higher proportions of patients with a good health state than regions with triage-based admission to SCU. These findings support evidence of Parker et al [20] and Ao et al. [48].

The association between adaptation of life and rehabilitation service time

In order to analyse the hypothesized relationships between rehabilitation services and adaptation of life (*H3*) we relate average time spent to rehabilitate patients to the mean value of adaptation of life in Figure 5-3. The results appear to invalidate the relationship between rehabilitation times and adaptation of life to impairments caused by stroke. The results don't confirm evidence of Mackenzie et al. indicating a positive effect of lengthier rehabilitation on AoL [50]. We therefore consider differences in three other aspects of rehabilitation services in section 3.2 to see if they can explain for differences in AoL below.

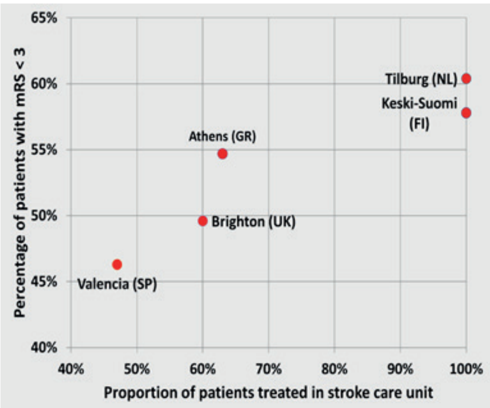

Figure 5-2 Relationship between direct admission to stroke care unit and health state at the time of survey

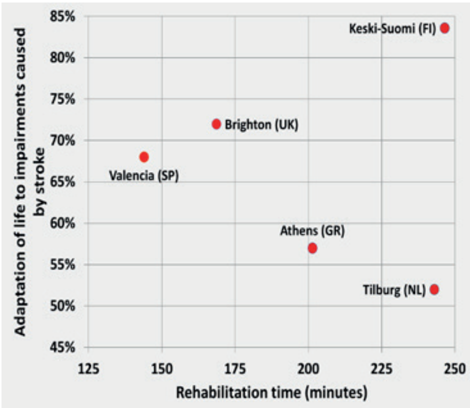

Figure 5-3 Relationship between rehabilitation time and adaptation of life to impairments

Table 5-10 Logistic regression analysis of health state at time of survey

		Step 1		Step 2		Step 3	
		OR	CI (95%)	OR	CI (95%)	OR	CI (95%)
1	Constant	6.91		17.04		15.42	
	Age	.96*	0.93-1.00	0.97	0.94-1.00	0.97	0.94-1.01
	Gender[a]	0.80	0.33-1.91	0.81	0.33-1.98	0.88	0.35-2.19
	Education[b]	.41*	0.18-0.95	0.46	0.19-1.1	0.46	0.18-1.13
	Alcohol consumption[c]	0.50	0.21-1.17	0.46	0.17-1.2	0.43	0.16-1.15
	Smoking[d]	0.35	0.1-1.32	0.34	0.09-1.31	0.28	0.07-1.19
	Health after stroke[e]	28.61**	10.87-75.31	30.80**	11.03-86.02	34.25**	11.73-100
2	Brighton			0.74	0.11-4.89	0.77	0.11-5.25
	Valencia			0.47	0.07-2.96	0.50	0.08-3.32
	Erlangen			0.34	0.05-2.24	0.33	0.05-2.23
	Athens			0.34	0.06-2.01	0.36	0.06-2.18
	Keski-Suomi			0.69	0.11-4.37	0.68	0.10-4.55
	Tilburg			0.00	0.00-0.00	0.00	0.00-0.00
3	Time from call to medical help arrives					1.00	0.99-1.01
	Time from onset to diagnosis					0.98	0.95-1.01
	$\Delta\chi^2$			3.25		1.92	
	Models χ^2	99.78***		103.03***		104.95***	
	-2 Log likelihood	159.89		156.64		154.72	
	Cox & Snell	0.41		0.42		0.43	
	Nagelkerke	0.55		0.56		0.57	

[a] 0=female, 1= male. [b] 0= minimum school leaving age, 1= more than minimum school leaving age. [c] 0= No alcohol consumption , 1=Alcohol consumption.
[d] 0= Non-smoker and former smoker, 1= smoker. [e] 0=State worse than "Symptoms, but able to carry out usual duties and activities after stroke",
1= State better than "Unable to perform all usual activities, but able to look after own affairs after stroke". *p<.05, **p<.01, ***p<.001

The association between service satisfaction and operations

Hypotheses *H5* to *H7* are tested using hierarchical regression models in Table 5-9. A basic set of demand and behaviour explains for 14% of the variance. In this step we control for age, gender, education, alcohol consumption, and smoking. In addition, we control for effects of health state at the time of survey as it is a predictor of service satisfaction [51]. In this analysis we first analysed *H5* which controls for the effects of regions as well as admission to stroke care unit that is a preliminary step to analyse *H4.* Step 2 tests *H5* regarding positive indirect effects of treatment in stroke care units and rejects *H5*. Step 3 tests *H4* which regards the effects of emergency response and the diagnosis speed (*H4*). The inclusion of response, diagnosis and stroke care unit does not significantly increase the explained variance and therefore *H4* is rejected. These findings do not support evidence of de Haan et al. [55] that shorter time to establish a diagnosis improves satisfaction with services.

Analysis regarding *H6* confirms that giving advice and possibility of discussions significantly increase the explained variance in service satisfaction; discussion of risk factors is the main driver. An analysis of the last hypothesis (*H7*) to explain satisfaction with services shows that the ServQual dimensions significantly increase the explained variance in service satisfaction by 29% (step 4 in Table 5-9). Therefore, this analysis confirms *H7*. This last regression model explains a total of 59% of variance in service satisfaction. Health state after stroke is the only demand variable which significantly contributed to the model ($\beta=0.15$, $p<.05$). Among the ServQual dimensions, tangibles and responsiveness significantly contribute to the model. Responsiveness has the largest contribution ($\beta=0.29$, $p<.05$). Interestingly, the other evidence based ServQual dimensions are not significant for stroke services.

From differences in operations to outcomes

We now consider operations of stroke care and identify notable differences between regions. Subsequently, we explore how differences in operations may affect outcomes. Data for dimensions of stroke service operations are given in Table 5-11 to Table 5-13. In the selection of data to present we rely on recommendation of Kjellström et al [6] and evidence of Parker et al. [20], which form a basis for the analysis logic. A full description of operations of regions is given in the case instance online additional file.

Following the disease progression logic we again begin the analysis by considering emergency response time and time until diagnosis. It can be seen that Brighton has the highest value for the majority of indicators for diagnosis (Table 5-11). It has the longest time from emergency department door to CT scan. This network has also the longest time to establish diagnosis as perceived by patients. To explore the effects of these differences on outcomes we suppose that fast response of emergency services and diagnosis extends the time window for eligible patients to receive thrombolysis [46]. We therefore hypothesize that:

H8: Shorter time until medical help arrival and shorter time from ED door to CT scan is positively associated with thrombolysis rate.

Table 5-11 Service operations in stroke provider networks

Regions		Keski–Suomi (FI)	Erlangen (G)	Athens (GR)	Tilburg (NL)	Valencia (SP)	Brighton (UK)	Total
Emergency response and diagnosis								
Time from ED arrival to CT–scan (hour)		0.6		0.25	0.5	0.78	2.6	
Door–to–door time in ED (hour)		4		3.8	2		4.8	
Time until medical help to arrive (minutes)	Mean	24.1	46.9	37.5	17.6	38.6	19.9	29.6
	SD	28.0	165.2	24.1	14.5	42.0	48.8	82.4
	N	82	87	44	84	35	72	404
Hours until diagnosis	Mean	3.8	4.9	2.3	5.3	8.0	7.6	5.3
	SD	6.4	14.2	4.3	18.5	17.1	23.7	16.0
	N	74	75	44	123	47	59	422
Ischemic treatment								
Ischemic treatment in dedicated stroke unit (%)		100	100	63	100	47	60	
Rate of thrombolysis (%)		8	15	3	14.3	8	6.3	

5

Next, a comparison is made between regions with regard to treatment in stroke care unit. There are differences in admission rate to SCUs between regions (See Table 5-11). However, we cannot support this comparison using statistical test as we do not have patient level data for this. Three regions Keski-Suomi, Tilburg, and Erlangen admit all patients facing stroke in a SCU. In contrast, Valencia, Athens, and Brighton are triage-based systems, in which only up to 60% of patients are treated in a stroke care unit. Treatment in a stroke unit is associated with a significantly lower mortality rate [56] and improved service outcomes e.g. thrombolysis rate [57]. We therefore hypothesize that admission to SCU may reduce mortality rate and also increase thrombolysis rate.

H9: More direct admission to SCUs is positively associated with thrombolysis rate.

H10: More direct admission to SCUs is negatively associated with mortality rate.

We learned in the previous section that while Keski-Suomi and Tilburg provide roughly the same amount of rehabilitation, they achieve remarkably different levels of AoL. Now, we consider other aspects of rehabilitation (Table 5-12) as hypothetical explanatory variables for AoL.

The aspects of rehabilitation in Table 5-12 show notable differences between regions, which may explain for difference in the AoL between regions. The differences in rehabilitation prescribed and received between regions are significant (rehabilitation prescribed: $p<0.001$; rehabilitation received: $p<0.001$). Furthermore, post-stroke consultations (giving advice and discussion on impact of stoke on life) are intended to assist patients in coping with impairments caused by stroke. We therefore hypothesize that:

H11: More prescribed, more received, and shorter waiting time to rehabilitation are positively associated with the AoL.

H12: There are positive relationships between advice and discussion concerning impact of stroke on life and AoL.

Table 5-12 Prescribed and received rehabilitation and waiting time to receive rehabilitation

		Keski–Suomi (FI)	Erlangen (GE)	Athens (GR)	Tilburg (NL)	Valencia (SP)	Brighton (UK)	Total
Rehabilitation prescribed[a]*	N	59	85	38	85	36	60	363
	%	36.2	69.1	65.5	41.3	38.3	56.1	48.3
	Total	163	123	58	206	94	107	751
Rehabilitation received[b]*	N	52	86	34	74	34	54	334
	%	67.5	92.5	79.1	69.8	60.7	80.6	75.6
	Total	77	93	43	106	56	67	442
Average waiting time until rehabilitation (days)	N	39	84	32	53	30	40	278
	Mean	15.6	8.8	10.8	48.4	15.8	11.6	18.7
	SD	19.1	22.0	26.6	110.1	16.8	18.0	53.3

[a] 0 = No rehabilitation is prescribed for patients, 1 = Rehabilitation is prescribed.

[b] 0 = No rehabilitation received, 1 = rehabilitation received

* Data from survey.

Our last hypothesis considers costs of stroke care. For international comparisons, costs are adjusted by purchasing power parity in the year 2011 (Table 5-13). Costs of patient journey including diagnosis, ischemic treatment, and rehabilitation vary from 4279 euros in Valencia to 8412 euro in Athens. We may assume that extra expenses result in better health, e.g. quality of life (Table 5-13).

H13: Higher cost of services is associated with more patients with a good health state (mRS) and higher EQ-5D utility.

Table 5-13 Costs of service journey and service user journey

Costs	Keski-Suomi (FI)	Athens (GR)	Tilburg (NL)	Valencia (SP)	Brighton (UK)
Diagnosis (S1)	1101	344	927	839	692
Treatment Ischemic stroke (S3)	5031	8011	4341	3250	4688
Rehabilitation (S4)	618	57	263	191	167
Average costs of ischemic stroke	6750	8412	5531	4279	5547

Below we test these hypotheses mostly using two-dimension graphs as the operational data mostly regard the network level instead of the patient level.

The association between emergency response and diagnosis and thrombolysis rate

We test *H8* in Figure 5-4 and Figure 5-5. In Figure 5-4 a relationship is established between waiting time to medical help arrival after the call and the proportion of patients receiving thrombolysis. Data for medical help arrival is derived from the surveys (health user perceptions) and data for thrombolysis come from provider information system.

The visual inspection of Figure 5-4 and Figure 5-5 does not present unambiguous support for *H8.*

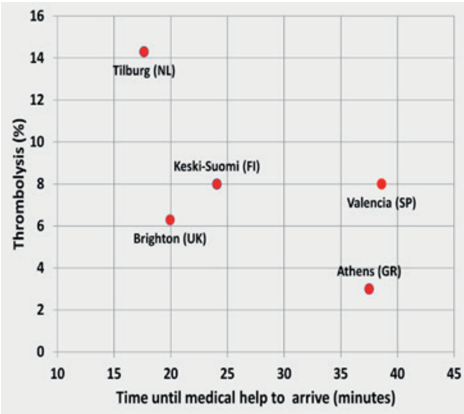

Figure 5-4 Relationship between emergency response and rate of thrombolysis

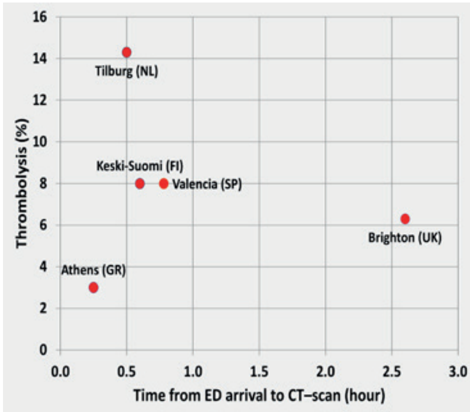

Figure 5-5 Relationship between ED door-CT scan time and rate of thrombolysis

Obviously, the performance of emergency response and diagnosis is not the only determinant of the thrombolysis rate. Geographical size of the region and the regional system of stroke care (centralization or decentralization) may influence response time and consequently influence thrombolysis rate [17]. Furthermore, the thrombolysis rate is to a great extent influenced by the availability of expert clinical staff to cover round the clock services [58].

The association between admission to stroke care unit and health outcomes

To investigate the hypothesis *H9* concerning the relationship between direct admission to stroke unit on the one hand and thrombolysis and mortality on the other hand we use aggregated data from provider information systems. We relate the admission rate to the SCU to the percentage of patients receiving thrombolysis in Figure 5-6 and to mortality rate in Figure 5-7.

Figure 5-6 shows that two of the three regions with a direct admission rate to the stroke units of 100% have higher rates of thrombolysis. These findings confirm previous evidence of Brainin et al. [47] and others [21, 46]. Figure 5-7 shows the links between the rate of admission to the stroke unit and the in-hospital mortality rate. The average mortality rate in the regions with an admission rate to the stroke units of 100% is less than half of the average mortality rate of the other regions. This finding confirms evidence of

Jorgensen et al. [56]. Let it be noted that Figure 5-6 and Figure 5-7 are not free of bias imposed by the uncontrolled demand and behaviour.

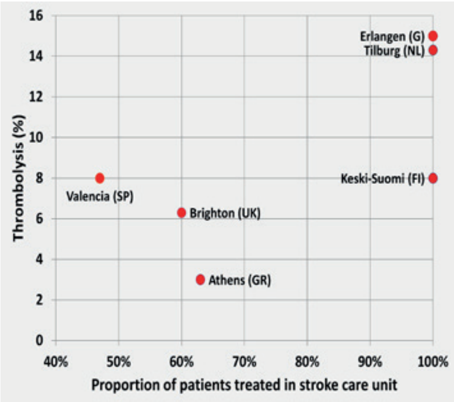

Figure 5-6 Relationship between treatment in stroke unit and rate of thrombolysis

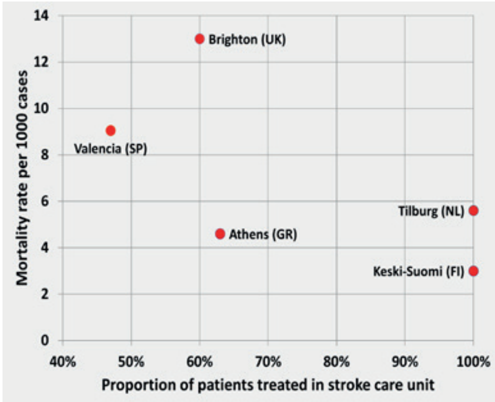

Figure 5-7 Relationship between treatment in stroke unit and mortality rate (per 1000 stroke cases)

The association between rehabilitation services and post-stroke consultation and adaptation of life

A hierarchical regression analysis is given in Table 5-14 to test *H11* and *H12*. Step 1 of the analysis controls for demand characteristics and step 2 controls for effects of treatment in stroke care unit.

Having controlled for demand, behaviour, and stroke care design, which explain for 14% of variance in adaption of life, the effects of rehabilitation on the AoL is tested (step 3 in Table 5-14). This analysis shows that inclusion of the aspects of rehabilitation service to the regression model increases the explained variance in AoL. This improvement is statistically significant. This analysis therefore confirms hypothesis *H11*. When rehabilitation is prescribed for patients compared with no prescribed rehabilitation, positive effects on adaptation have been shown; whereas, longer waiting time to receive rehabilitation has a negative effect on adaptation of life. The long waiting time may therefore partly explain the lower value of AoL in Tilburg. Somewhat surprisingly, step 4 in Table 5-14 rejects the hypothesis that counselling and discussion impacts adaptation of life.

The associations between costs and health outcomes

To test *H13* we relate costs of treatment per stroke patient to the percentage of patients with mRS > 3 (Figure 5-8) and EQ-5D utility and at the time of survey (Figure 5-9). Visual inspection does not confirm any relationship between costs and mRS, EQ-5D at the network level. The networks with the highest and lowest costs both achieve the lowest average quality of life.

Table 5-14 Hierarchical regression analysis of adaptation of life to impairment caused by stroke

	Variables[1]	β Step 1	Step 2	Step 3	Step 4
1	Age	-.13	-.13	-.14*	-.14*
	Gender[a]	.00	.00	.02	.01
	Education[b]	.19**	.19**	.17*	.17*
	Alcohol consumption[c]	.14	.14	.16*	.16*
	Smoking[d]	-.08	-.08	-.08	-.08
	Health status at the time of survey[e]	.13	.13	.13	.12
2	Stroke care design[f]		-.02	-.02	-.01
3	Rehabilitation prescribed[g]			.30*	.29*
	Rehabilitation received[h]			-.08	-.08
	Waiting time for rehabilitation			-.14*	-.14*
4	Advice on impact of stroke on life				.02
	Discussion advice				.03
	ΔR^2		.00	.07	.00
	R^2	.14	.14	.21	.21
	F change	4.82**	.09	5.37**	.20
	df1	6	1	3	2
	df2	185	184	181	179

[a] 0=female, 1= male. [b] 0= minimum school leaving age, 1= more than minimum school leaving age.
[c] 0= No alcohol consumption , 1=Alcohol consumption. [d] 0= Non-smoker and former smoker, 1= smoker.
[e] 0=State worse than "Symptoms, but able to carry out usual duties and activities after stroke", 1= State better than "Unable to perform all usual activities, but able to look after own affairs after stroke".
[f] 0= Triage-based design, 1= Stroke care unit-based design.
[g] 0 = No rehabilitation is prescribed for patients, 1 = Rehabilitation is prescribed.
[h] 0 = No rehabilitation received, 1 = rehabilitation received
*p<.05, **p<.01; (standardized coefficient, listwise, two-tailed)

Discussion and conclusions

This study aims to provide an evidence base to advance understanding on the relationships between health services and outcomes in stroke care provider networks following the methodology presented in Mahdavi et al. [28]. Our study explains outcomes using demand, behaviour and operations (where operations are modelled by structures and services) for health state (mRS) at the time of survey, adaptation of life to impairments (AoL), and satisfaction by respectively 43%, 21%, and 59%. Operations account for resp. 2%, 7%, and 46% of the combined explained variance. The ServQual variables tangibles and responsiveness are significant and together explain 29% of satisfaction with services. The other included ServQual items were however non-significant.

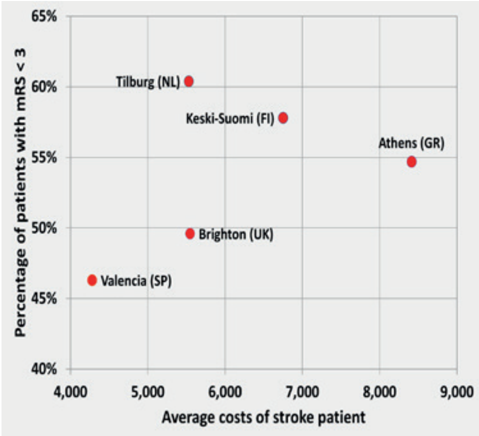

Figure 5-8 Relationships between average costs of service (adjusted by PPP for 2011) and health state at the time of survey (measured by mRS)

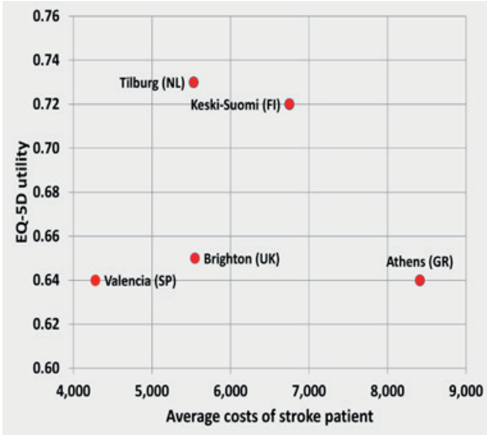

Figure 5-9 Relationships between average costs of service (adjusted by PPP for 2011) and EQ-5D utility score

In discussing the findings we follow the logic of the service user journey starting from speed of emergency response and diagnosis to stroke care design and rehabilitation services. The speed of emergency response and time until diagnosis explain differences in the health state–at patient level analysis– and thrombolysis as intermediate outcomes –at network level analysis. We find that delay in emergency response and diagnosis is associated with lower health value and decreased thrombolysis rate decreases. These findings confirm previous research and best practice stroke care [59] regarding speed of emergency response and diagnosis.

An important operational distinction is formed by the two types of stroke care designs at network level. Table 5-15 summarizes differences between stroke unit based networks and triage based networks. The pertinent differences regard the percentage of direct admission to the stroke care unit, thrombolysis rate, and rehabilitation service time. Overall, it appears that evidence based service operations are provided more frequently in stroke care unit-based regions than in triage-based regions.

The analysis at patient level does not recognize the effects of more direct admission to stroke care unit on outcomes particularly on the health state (mRS). The results of this study provide different evidence at the patient level and at the network level. The results at the network level, although less rigorous suggest that admission to the stroke care unit is positively associated with the health state (mRS) at time of survey. Our findings at network level also suggest stroke care unit based networks yield higher thrombolysis rates. The relationships between operations and outcomes need not necessarily be a causal relationship from operations to outcomes. For example worse outcomes before starting rehabilitation may lead to higher costs of rehabilitation. This is a possible explanation for the ambiguous effect on outcomes of costs and rehabilitation effort found in the analysis. We may therefore conclude that Donabedian's unidirectional structure-process-outcomes model which serves as a basis for the model applied in this research is too simple to explain some of the important phenomena relating operations and outcomes in stroke networks.

Table 5-15 Summary of differences between two types of stroke care design

	Indicators	Stroke care unit-based regions	Triage based-regions
Speed	Minutes until medical help to arrive (survey)	19.1	21.9
	Hours until diagnosis (survey)	4.8	4.3
Treatment	Direct admission to stroke care unit	100	57
Thrombolysis	Thrombolysis rate (%)	12%	5.8%
Advice and discussion	Advice impact of stroke on life (s.)	65%	52%
	Discussion impact of stroke on life	43%	36%
	Advice concerning risk factors (s.)	61%	50%
	Discussion advice concerning risk factors	57%	45%
Rehabilitation	Rehabilitation prescribed (s.)	49%	37%
	Rehabilitation received	95%	72%

This study has some limitations. First, this study mostly addresses the service provisioning challenges in urban areas. These areas may have different demography and infrastructure therefore posing different challenges such as emergency response to providers. Second, we used the mRS instrument which is a clinician-reported health outcome measure, and adapted it for self-reporting. As one may expect that the clinical outcomes mediate between service operations and quality of life, further exploration of the relationships between health service operations and clinical outcomes on the one hand, and clinical outcomes and quality of life on the other hand, is also worthy of further exploration.

The stroke model derived from the generic model provides a generic template for replicable description and comparison of the performance of stroke networks as called by Price et al. [60]. The detailed operational stroke model successfully established a first evidence based on the relation between operations and outcomes for stroke networks. Satisfaction is largely explained, however, the relationships between operations and health outcomes leave much room for further understanding. Future refinement of the model is therefore called for. Likewise, the analysis at network level sometimes suffers from the relatively small number of networks, causing it to deviate from the presented or earlier analysis with patient level data. Extending the research to a broader set of regional networks may therefore further strengthen the findings and evidence at network level. Subsequent publications from the Managed Outcomes project will address application of the generic model to other diseases and cross disease comparison.

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Appendix

The purpose of this appendix is to describe the operations in five case instances of stroke provider networks. These networks are modelled as instances of the Stroke model, defining operations, behaviour, and outcomes. An instance is derived from the Stroke model which defines *Service* and underlying *Structure* that are provided to meet patient *Demand*. In the description of these entities we focus on the most relevant subcomponents for provider networks.

Demand

According to the Stroke model three aspects of demand are important: demand location, demand segment, and demand characteristics. We do not further distinguish demand location into, for instance, urban or rural areas. Among the demand for stroke care we focus in the paper only on cerebral infarction (ischemic stroke) as the demand segment in this research given its burden. We then distinguish this segment into two sub-segments with potentially different services and structure (See Table 5-16): patients with ischemic stroke attended in a stroke unit (DS4a) and patients diagnosed with ischemic stroke not attended in a stroke unit (DS4b).

Table 5-16 Demand for stroke care

	Keski-Suomi (FI)	Erlangen (G)	Athens (GR)	Tilburg (NL)	Valencia (SP)	Brighton (UK)
Total stroke cases (excl TIA)	776	771	176	1218	846	724
Cases (DS4, ischemic)	538	508	150	676	478	449
via stroke unit (DS4a)	538 (100%)	508 (100%)	94 (63%)	676 (100%)	225 (47%)	270 (60%)
direct to ward (DS4b)			56 (37%)		253 (53%)	179 (40%)
Cases (DS3, haemorrhagic)	238	105	26	88	285	130
Cases (DS2, TIA)		158	5	454	83	145
Incidence / 100000 (DS4, ischemic)	197	110	107	198	179	123
Incidence / 100000 (DS3, hemorrhagic)	87	23	19	26	107	36

Characteristics of a sample of stroke patients in the studied regions are given in Table 5-16 and Table 5-17.

Services

Service elements provided in the regions are shown in Table 5-18. We are unable to present service elements for all regions, we therefore present data for three regions.

As defined in the Stroke model, the services for a demand segment constitute a service journey. The service journey for the ischemic demand segment consists of three services: diagnosis (S1), ischemic treatment (S2) and rehabilitation (S3). Each of these services consists of a set of service elements (See Table 5-19).

Table 5-17 Characteristics of a sample of stroke patients living in the regions

Regions	Keski–Suomi	Erlangen	Athens	Tilburg	Valenc-ia	Brigh-ton	Total
Age							
Mean	69.8	67.5	72.9	70.2	66.4	74.7	70.1
Std. Deviation	12.4	13.2	10.6	12.6	12.3	10.4	12.4
N	182	116	64	221	99	115	797
Gender							
N(female)	77	38	28	82	26	29	280
%	52.0	38.8	53.8	39.8	37.1	33.0	42.4
Education							
minimum school leaving age	59	30	31	76	62	54	312
	37.6%	27.3%	52.5%	39.0%	67.4%	49.5%	43.2%
more than minimum school leaving age	98	80	28	119	30	55	410
	62.4%	72.7%	47.5%	61.0%	32.6%	50.5%	56.8%
Total	157	110	59	195	92	109	722
Time since last stroke							
N	190	126	65	224	101	120	826
Mean	14.9	16.7	11.4	7.5	18.2	10.1	12.6
SD	3.4	3.7	5.2	3.8	3.9	3.7	5.5
Previous stroke							
N	163	120	62	209	89	106	749
Mean	0.31	0.23	0.35	0.47	0.39	0.53	0.38
SD	0.87	0.63	0.73	1.09	1.01	0.94	0.92

The service journeys in Table 5-19 are from the Stroke model. The percentage of patients using these service elements per service in the regions can vary. Not all regions use all service elements in each service. Table 5-20 shows percentage of use of diagnosis service elements.

As shown in Table 5-20 until basic diagnostic test ED (SE6) regions provide roughly the same percentage. Use of CT scan and MRI is different between regions. In three regions Keski-Suomi, Tilburg, and Brighton use of MRI is not reported. Use of CT scan in Athens largely differs from other regions.

The percentage of patients who use service elements for treatment ischemic service are given in Table 5-21. Percentages of patients who use anti-aggregation, stroke care unit, and neurological ward vary between regions, most obviously between Brighton and other regions.

In Table 5-22 percentages of patients who use rehabilitation service elements are given. Table 5-22 shows that use of physiotherapy gym and dietician is reported at Brighton and Tilburg respectively.

Table 5-18 Service elements in regions

Athens (GR)	Tilburg (NL)	Valencia (SP)
Symptoms identification	Symptoms identification	Symptoms identification
Ambulance	Ambulance	Ambulance
Primary care visit/Family Internist visit	Family Physician/GP	Primary care visit
Emergencies department care	Emergency room care	Emergencies department care
Neurologic exploration	Neurologic exploration	Neurologic exploration
Basic diagnostic test	Basic diagnostic test ED	Basic diagnostic test
Perfusion CT	Perfusion CT	Perfusion CT
Angio CT	Angio CT	Angio CT
Anti-aggregation	Anti-aggregation	Anti-aggregation
Anti-coagulation	Anti-coagulation	Anti-coagulation
Thrombolysis	Thrombolysis	Thrombolysis
Referral for Neurosurgery	Neurosurgery	Neurosurgery
Discharge	Discharge	Hospital at Home care
Basic diagnostic test	Basic diagnostic test ward	Discharge
Detailed neurologic exploration	Image diagnostic test: MRI or CT-Scan	Basic diagnostic test
Image diagnostic test: MRI or CT-Scan	Additional image diagnostic test	Detailed neurologic exploration
Additional image diagnostic test	Cardiologic test	Image diagnostic test: MRI or CT-Scan
Cardiologic test	Other tests: eeg and arteriography	Additional image diagnostic test
Other tests: eeg and arteriography	Carotid angioplasty	Cardiologic test
Referral Carotid angioplasty	Stroke unit care	Other tests: eeg and arteriography
Stroke unit care	Neurology ward care	Carotid angioplasty
Internal medicine ward care	Neurosurgery ward care	Stroke unit care
Intensive care	Intensive care	Neurology ward care
RHB physician exploration	RHB physician exploration	Neurosurgery ward care
Physiotherapy bedside	Physiotherapy bedside	Intensive care
Speech therapy physician exploration	Speech therapy physician exploration	RHB physician exploration
Speech therapy	RHB ward care	Physiotherapy bedside
Social worker	Physiotherapy gym	Speech therapy physician exploration
1st Follow up	Occupational therapy	RHB ward care
	Speech therapy	Physiotherapy gym
	Social worker	Occupational therapy
	UMCE care	Speech therapy
	Carotid endartectomy	Social worker
	Intra-arterial Sstroke therapy	UMCE care
	Acceleration of blood coagulation	Endartectomy
	Surgery ward	
	Dietician	
	Activity support	
	Rehabilitation	

Table 5-19 Service elements per service journey

Diagnosis journey	Treatment Ischemic stroke journey	Rehabilitation journey
Symptom identification (SE1)	Anti-aggregation (SE9)	RHB physician exploration (SE26)
Ambulance (SE2)	Anti-coagulation (SE10)	Physiotherapy bedside (SE27)
Primary care visit (SE3)	Thrombolysis (SE11)	Speech therapy physician exploration (SE28)
ED care (SE4)	Intra-arterial stroke therapy	Physiotherapy gym (SE30)
Neurological exploration (SE5)	Carotid angioplasty (SE21)	Occupational therapy (SE31)
Basic diagnostic test ED (SE6)	Endartectomy (SE35)	Activity support
Perfusion CT (SE7)	Stroke unit care (SE22)	Speech therapy (SE32)
Angio CT (SE8)	Neurology ward care (SE23)	Social worker (SE33)
Image diagnostic test CT-scan (SE17)	Internal Medicine /Medical ward	Dietician
Image diagnostic test MRI (SE17)	Ward for patients waiting for follow-up	
Basic diagnostic test ward (SE15)	UMCE care (SE34)	
Detailed neurological exploration (SE16)	Intensive care (SE25)	
Additional image diagnostic test (SE18)		
Cardiologic test (SE19)		
Other tests: EEG (S20)		
Other tests: arteriography (S20)		

Table 5-20 Percentage of patients who use service elements for diagnosis (S1)

Diagnosis	Keski-Suomi	Athens		Tilburg	Valencia		Brighton	
		DS4a	DS4b		DS4a	DS4b	DS4a	DS4b
Symptom identification (SE1)	100	100	100	100	100	100	100	100
Ambulance (SE2)	100	100	100	85	80	80	80	80
Primary care visit (SE3)	10	10	10	10	10	10	10	10
ED care (SE4)	100	100	100	100	100	100	100	100
Neurological exploration (SE5)	100	100	100	100	100	100	100	100
Basic diagnostic test ED (SE6)	100	100	100	100	100	100	100	85
Perfusion CT (SE7)				1	1	1		
Angio CT (SE8)		3	2	1	0.5	0.3	1	1
Image diagnostic test CT-scan (SE17 a)	100	56	41	100	95	95	95	95
Image diagnostic test MRI (SE17 b)		17	33		75	75		
Basic diagnostic test ward (SE15)	100	100	100	100	100	85	100	85
Detailed neurological exploration (SE16)	100	100	100		100	85	100	85
Additional image diagnostic test (SE18)		72	75	95	10	10	70	70
Cardiologic test (SE19)		36	30	15	20	15	20	20
Other tests: EEG (SE20)	3	3	5	5	3	3		
Other tests: arteriography (SE20)					5	5		

Table 5-21 Percentage of use in treatment ischemic service (S2)

Treatment Ischemic stroke (S3)	Keski-Suomi	Athens		Tilburg	Valencia		Brighton	
	DS4	DS4a	DS4 b	DS4	DS4a	DS4b	DS4a	DS4b
Anti-aggregation (SE9)	100	100	100	95	85	70		
Anti-coagulation (SE10)	8	4	2	5	1	10	1	10
Thrombolysis (SE11)	8	3		8	8	0	8	
Intra-arterial stroke therapy				5				
Carotid angioplasty (SE21)	1	2	2	1	1	1	1	
Endartectomy (SE35)	5	5	5	5	1	1	1	1
Stroke unit care (SE22)	100	100		100	100		100	
Neurology ward care (SE23)	100			100	85	95		
Internal Medicine / Medical ward			100					100
Ward for patients waiting for follow-up	100			100				
UMCE care (SE34)					5	5		
Intensive care (SE25)	1	2	2	1	1		1	

Table 5-22 Percentage of service element use in rehabilitation service (S3)

Rehabilitation	Keski-Suomi	Athens		Tilburg	Valencia		Brighton	
		DS4a	DS4b		DS4a	DS4b	DS4a	DS4b
RHB physician exploration (SE26)	95	98	30	95	80	70	80	50
Physiotherapy bedside (SE27)	100	100	30	95	80	70	80	50
Speech therapy physician exploration (SE28)	50	49	20		32	20	32	20
Physiotherapy gym (SE30)							16	8
Occupational therapy (SE31)	10			5			15	8
Activity support				10				
Speech therapy (SE32)	50	49	20	40	32	20	40	25
Social worker (SE33)	5	2	4	5	5	3	5	3
Dietician				50				

Percentage of patients using service elements and sequential relationships between service elements create a service user journey that can vary between regions. We do not have data for the sequence of service elements for all networks, however the main flow is roughly the same. As an example, in Figure 5-10 a service journey for stroke patients in Tilburg is illustrated. A stroke event is identified by a patient/patient relative, and further endorsed by a family doctor or GP. Then, patients are transferred to an emergency department. In a further step the diagnosis service is provided. Service elements for diagnosis are red-colour boxes in Figure 5-10.

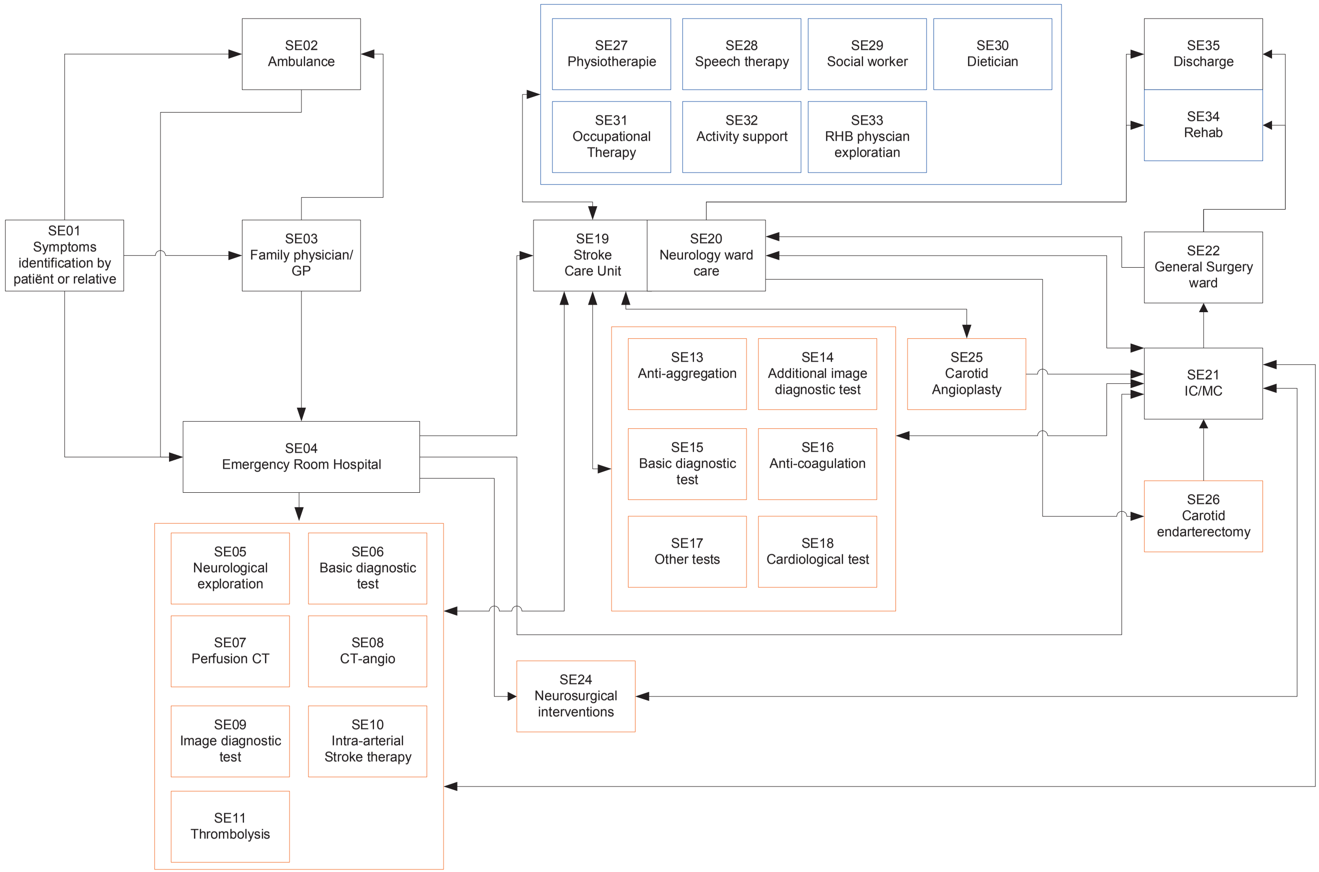

Figure 5-10 Service journey for the ischemic demand segment (DS4) (This figure includes service elements for DS3 and DS4, the numbering of service elements may differ from numbers in Table 5-19).

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Service elements for diagnosis service are also similar for haemorrhagic patients (DS3). Next, patients receive ischemic treatment (See Table 5-19). The third service in the ischemic service journey is rehabilitation service. Service elements for rehabilitation service are coloured blue in Figure 5-10.

Structure

The structure for stroke care considers the use of the stroke care unit and resources. Three regions Keski-Suomi, Tilburg, and Erlangen admit all patients facing stroke in a stroke care unit. Service elements for treatment of ischemic stroke are provided in such units by multidisciplinary team of professionals. In contrast, Valencia, Athens, and Brighton are triage-based systems, in which only up to 63% of patients are treated in a stroke care unit.

Per service element a resource is defined which has a type and a unit of measurement (time or number). Duration of time or service time assigned to provide the service elements is the most occurring resource unit for service elements of ischemic stroke. Another indicator for comparison makes use of "usage X duration" per service element to calculate amount of resource use time.

Service use per service element of stroke services is given in Table 5-23, Table 5-24, and Table 5-25. Table 5-23 shows that Brighton provides less service time on average. In this region some of diagnostic tests are not provided and for some others that are provided, the average use is lower than in other regions.

As shown in Table 5-24 in any case all regions provide stroke unit care. For patients not attended in stroke care unit in triage-based regions, care is provided in either a neurological ward or an internal medicine/medical ward. Athens and Brighton do not provide neurological ward care. A higher average service use per patient in triage-based regions could be caused by the fact that only severe patients are attended in a stroke care unit in these regions.

For calculation of the service time for rehabilitation we do not include RHB physician exploration as time used for rehabilitation but as time for planning. The totals in Table 5-25 therefore exclude this service element.

Cost per service and service journey (total costs of ischemic stroke) in a region is also calculated using "usage X amount of resource per element X cost per resource unit." Using this information facilitates producing average costs per patient at region level (Table 5-26). Usage, amount of resource per element, and unit cost of resource are trigger for differences in service use and costs between regions and therefore topic for analysis and comparison between regions. The cost data presented in Table 5-26, Table 5-27, and Table 5-28 is not adjusted by purchasing power parity and therefore cannot be compared between regions.

Table 5-23 Average use of service elements in diagnosis service (S1)

	Keski-Suomi	Athens		Tilburg	Valencia		Brighton	
	DS4	DS4a	DS4b	DS4	DS4a	DS4b	DS4a	DS4b
Diagnosis (S1)								
Symptom identification (SE1)	1			1	1	1	1	1
Ambulance (SE2)	60	68	68					
Primary care visit (SE3)	1	2	2	1	1	1	1	1
ED care (SE4)	20	20	20	10	10	10	10	10
Neurological exploration (SE5)	10	10	10		10			
Basic diagnostic test ED (SE6)	15	20	20	15	15	15	15	13
Angio CT (SE8)		0		0.1	0.0		0.1	0.1
Image diagnostic test CT-scan (SE17)	40	17	12	40	38	38		
Image diagnostic test MRI (SE17)					30	30		
Basic diagnostic test ward (SE15)	15	60	60	15	15	13	10	9
Detailed neurological exploration (SE16)	20	20	20		45	38		
Additional image diagnostic test (SE18)		22	23	29	3	3	21	21
Cardiologic test (SE19)				5	6	5	6	6
Other tests: EEG (SE20)	3.6	4	6		4	4		
Other tests: arteriography (SE20)					2	2		

Table 5-24 Average use of service elements in treatment of ischemic stroke (S2)

Treatment Ischemic stroke (S3)	Keski-Suomi	Athens		Tilburg	Valencia		Brighton	
	DS4	DS4a	DS4b	DS4	DS4a	DS4b	DS4a	DS4b
Anti-aggregation (SE9)				1				
Anti-coagulation (SE10)								
Thrombolysis (SE11)	4.8	4		5	5		5	
Intra-arterial stroke therapy				8				
Carotid angioplasty (SE21)	1.8	4	3	1	2	2	2	
Endartectomy (SE35)	4.23	5	5	5	1	1	1	1
Stroke unit care (SE22)	2880	17856		5760	4320		15264	
Neurology ward care (SE23)	8640			10080	6120	13680		
Internal Medicine / Medical ward			14400					19008
Ward for patients waiting for follow-up	4320			4320				
UMCE care (SE34)					144	144		
Intensive care (SE25)	40	144	130	58	58		58	

Table 5-25 Average use of service elements in rehabilitation service (S3)

Rehabilitation	**Keski-Suomi**	**Athens**		**Tilburg (NL)**	**Valencia (SP)**		**Brighton (UK)**	
	DS4	DS4a	DS4b	DS4	DS4a	DS4b	DS4a	DS4b
RHB physician exploration (SE26)	57	29	9	29	24	21	24	15
Physiotherapy bedside (SE27)	150	210	64	114	96	147	96	60
Speech therapy physician exploration (SE28)	15	15	6		10	6	10	6
Physiotherapy gym (SE30)							24	12
Occupational therapy (SE31)	20			10			30	16
Activity support				18				
Speech therapy (SE32)	75	58	24	48	19	18	48	30
Social worker (SE33)	1.5	1	1	3	3	2	3	2
Dietician				50				
Total	319	313	104	272	152	194	235	141

Table 5-26 Average costs per patient in diagnosis service (S1)

Diagnosis (S1)	**Keski-Suomi**	**Athens**		**Tilb-urg**	**Valencia**		**Brighton**	
	DS4	DS4a	DS4b	DS4	DS4a	DS4b	DS4a	DS4b
Symptom identification (SE1)								
Ambulance (SE2)	500	38	38	264	248	248	248	248
Primary care visit (SE3)	9	4	4	10	10	10	10	10
ED care (SE4)	302	11	11	180	124	124	124	124
Neurological exploration (SE5)	0	40	40					
Basic diagnostic test ED (SE6)	250	84	84	190	209	209	209	178
Perfusion CT (SE7)				1	4			
Angio CT (SE8)		2	1		1		2	2
Image diagnostic test CT-scan (SE17)	175	36	26	142	124		124	124
Image diagnostic test MRI (SE17)								
Basic diagnostic test ward (SE15)	100	31	31	130	67	57	67	57
Detailed neurological exploration (SE16)	50	40	40					
Additional image diagnostic test (SE18)		47	19	135	13	13	91	91
Cardiologic test (SE19)		12	10	19	40	30	40	40
Other tests: EEG (SE20)	1.5	0.2	0.3		1.6	1.6		
Other tests: arteriography (SE20)					59.6	59.6		

Table 5-27 Average costs per patient in treatment of ischemic stroke (S2)

Treatment Ischemic stroke	Keski-Suomi	Athens		Tilburg	Valencia		Brighton	
	DS4	DS4a	DS4b	DS4	DS4a	DS4b	DS4a	DS4b
Anti-aggregation (SE9)								
Anti-coagulation (SE10)								
Thrombolysis (SE11)								
Intra-arterial stroke therapy				455				
Carotid angioplasty (SE21)	5	7	6	3	6	6	6	
Endartectomy (SE35)	235	311	313	293	130		455	
Stroke unit care (SE22)	2600	8196	0	1647	1752		4770	
Neurology ward care (SE23)	3000			2096	1359	3037		
Internal Medicine / Medical ward			5596					5280
Ward for patients waiting for follow-up	450			450				
UMCE care (SE34)					22	22		
Intensive care (SE25)	48	176	158	69	48		48	

Table 5-28 Average costs per patient in rehabilitation service (S3)

Rehabilitation	Keski-Suomi	Athens		Tilburg	Valencia		Brighton	
	DS4	DS4a	DS4b	DS4	DS4a	DS4b	DS4a	DS4b
RHB physician exploration (SE26)	86	13	4		75	65	75	47
Physiotherapy bedside (SE27)	380	42	13	125	63	97	63	40
Speech therapy physician exploration (SE28)	45	6	3		30	19	30	19
Physiotherapy gym (SE30)	0						16	8
Occupational therapy (SE31)	45			8			10	5
Activity support								
Speech therapy (SE32)	223	12	5	74	10	10	26	16
Social worker (SE33)	2			5	3	2	3	2
Dietician				92				

Chapter 6

Modelling and Evaluation of Hip Osteoarthritis Service Provider Networks

This chapter is based on:

Mahdavi, M., Vissers, J., van de Klundert, J., Konerding, U., Elkhuizen S., Torkki, P., Bowen, T. Faubel, R., Pavi, E., Modelling and evaluation of hip osteoarthritis service provider networks.

This paper is in progress for submission.
Submission is conditional on the outcome of review of the papers in chapters 3 and 4.

Abstract

Background: This study explores the associations between operations and outcomes in order to develop an evidence base for the management of hip osteoarthritis (hip OA) service provider networks.

Method: The models and methods proposed in our previous research have been used as a basis to develop a Hip OA model for describing the operations in hip osteoarthritis service provider networks and to analyse the relationships between operations and outcomes. The Hip OA model is subsequently applied to describe health service operations and outcomes in three hip OA service provider networks in European countries. Relationships between differences in operations and differences in health and service outcomes are explored at patient level and network level.

Results and discussion: We analysed the relationships with pain, impaired usual activity, health related quality of life by EQ-5D, and service satisfaction. For a population with diverse demographic characteristics a longer waiting time until surgery is found to deteriorate pain but not usual activity. For the diverse EU populations considered in this study, patient characteristics explain for almost all explained variance in pain and impairments. However, with regard to EQ-5D 16 out of 19% of the explained variance is attributed to operations, mostly via the ServQual dimensions. Service satisfaction is found to be related to operations in a different manner. Operational differences explain 30% out of 33% explained differences in satisfaction with services. Satisfaction decreases by an increase in impairments but is not associated with changes in pain.

Conclusions: The model provides an initial basis to relate differences in health outcomes with differences in health service network operations. The explained variance is largely explained by differences in operations, although the explained variance in quality of life is limited. The models form a basis to advance the evidence base and understanding of provider networks for hip OA care, more so when considered in relation to models for diabetes and stroke, which are derived from the same generic model.

Keywords: Hip Osteoarthritis, Provider Networks, Operations Management, Outcomes

Background

Hip osteoarthritis (hip OA) is the second most common type of osteoarthritis, which affects bones, cartilage and surrounding tissues of the hip. Pain, stiffness and severe disability are common complaints of hip OA patients [1]. The current trend of population aging, obesity, and limited exercise leads to a constant increase in the number of people suffering from hip OA [2]. In Europe and North America 10.1% and 7.2% of population respectively live with consequences of hip OA [1]. The most common treatment is total hip replacement [3], which is growing rapidly in the United States and other developed countries. The expectation is that in the United States, primary hip operations because of arthritis will grow by 174%, to 572,000 per year by 2030 [4]. A large amount of costs incurs to operate this patient group; the mean costs of operations in nine European countries is estimated around € 5043 [5]. However, the total costs of hip OA far exceed surgical costs by costs incurred by conservative care, loss of productivity, patient discomfort, and other social costs [6].

Hip OA is a chronic condition which requires long term care with continuity of sustained relationships with providers [7]. In the treatment of hip OA various service providers may be involved. Professionals including physiotherapist, social support staff, and/or case manager are involved in the care plan to reduce the likelihood of progression or slow down the progression of the disease [8]. In the operative phase in an acute hospital, other medical and nursing staff will be involved in service delivery. As none of these providers are able to independently meet the hip OA patient demand, provider networks have become a popular trend in service provisioning for hip OA patients [9]. Providers form networks to provide the entire continuum of hip OA services in a geographical region. Provider networks may be formally defined as a collection of providers that work together to improve patient outcomes or be informally defined as a collection of providers visited by a group of hip OA patients [10]. Outcomes of provider networks depend on the operations of the whole network or a small number of providers that perform most of service provisioning tasks [10, 11].

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Operations of provider networks are defined as health services that consume resources to improve health outcomes [12]. There is only limited evidence available - in the form of either theoretical service operational models or empirical findings - that considers service operations of hip OA. A systematic review by Zwar et al. [13] found that the number of service delivery models extending chronic care models to hip-OA is low; eight studies on service models for OA including hip OA compared to 54 studies on diabetes. This limited number of applied chronic care models for hip OA often focus on patient self-management [14]. Only two studies report well-described service models for OA in Australian populations [15]. In the few available service models, effects of service operations on service outcomes such as in-hospital length of stay are described. For relationships between operations and patient outcomes existing evidence is conflicting. For instance, associations between waiting time and pain and physical function in some studies are positive and in some others studies negative [16]. Therefore evidence on the effects that operational components have on outcomes such as pain and patient mobility need to be further explored [17].

This study aims to analyse operations of hip OA service provider networks in five European countries in order to develop an evidence base for management of hip OA service operations. More specifically we contribute to advancing the understanding of the interrelationships between operations and outcomes. The work is based on the EU FP7 project Managed Outcomes, and the corresponding framework and research methodology [12]. The framework and methodology enable a comparative analysis of health service operations against outcomes and support replication in different settings , thus responding to calls of Wagner et al. [18], Berwick [19], and the British Medical Council [20], to advance the scientific understanding of health service operations networks.

The outline of this study is as follows. In Method section we present the aforementioned framework and methodology and outline the study design and methods. Results section presents the analysis results. We then present our discussion, conclusions, and recommendation for future research. The paper appendix provides information on the Hip OA model. In the additional file 1 [21] more information is found on the case instances and the data collected on operations and outcomes.

Methods

The present study builds on the framework for modelling and analysis of health operations in provider networks in Mahdavi et al. [12]. This framework enables to develop generally applicable models for health service operations. To this purpose the framework offers generic level entities to specify health service operations, and a disease-specific level at which entities are added to the generic level, or generic model entities are redefined. The Hip OA model is then instantiated at two types of instances, namely network instances (to enable modelling of the networks) and health service user instances (to enable modelling of health service users). We refer to Mahdavi et al. [12] for a detailed description of the framework, and restrict the present paper to the modelling of provider networks for hip OA, and the patients in these networks. In the remainder we refer to the disease-specific model for the network of health service operations for hip OA by the Hip OA model. We use the term patients rather than health service users, and we refer to the five network instances occurring in the empirical FP7 study by the name of the region, e.g. Tilburg or Valencia.

The Hip OA model inherits the five core entities for modelling of health service operations from the generic model: demand, services, structure, behaviour, and outcome (see Figure 6-1). The generic model captures the current scientific understanding that outcomes are not solely determined by service provisioning but that health behaviour and health conditions (demand) interact with the service provisioning processes and structures, and that service provisioning, health conditions and health behaviour jointly affect outcomes.

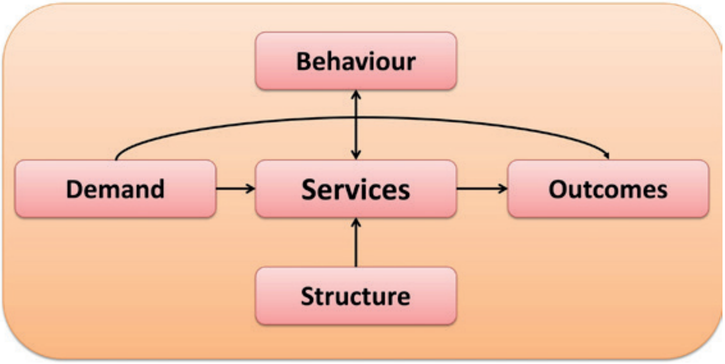

Figure 6-1 Relationships between demand, services, structure, behaviour and outcomes

In Table 3-1 the (generic) components of the five core entities of the operational model in Figure 6-1 are further elaborated.

The Hip OA Model

A hip OA network serves a population of hip OA patients living in a region that can be distinguished to demand locations, for instance urban and rural areas (Table 6-1). Demand for services can be described as segments that share the same characteristics. Within this model only one demand segment is defined, i.e. patients with hip OA in need of treatment, as this is in accordance with the demarcation used in the Managed Outcomes project. The model then describes the characteristics of the population of the patients. These characteristics include age, gender, education, body mass index (BMI), time since surgery, and previous surgery. These variables capture differences in patients' characteristics which lead to differences in outcomes [22]. In the additional file 1 [21] we present more details on the Hip OA model. We furthermore present in the additional file 1 [21] detailed descriptions of case instances.

The hip OA service provisioning is subsequently defined by service elements, services, service journeys, and service user journeys [12]. A list of service elements as atomic units of a service entity [23] for hip OA is defined by guidelines on hip OA care [2]. A full list of service elements is given in the appendix. An ordered set of service elements constitutes a service, which in the Hip OA model are: diagnosis, conservative care, operative care, rehabilitation, follow-up, and referral for complications (Table 6-1). A set of services constitutes a user service journey, which is delivered to patients in the same demand segment. As the model only describes one demand segment there is only one user service journey.

We see from Table 6-2 that the diagnosis service is the point to make a decision about further services that are either operative care or conservative care. Patients who complete this operative care, subsequently receive follow up services. After the diagnosis, 25% of the patients receive conservative care and 75% undergo a surgical operation. After operative care all patient will receive follow up care, however 5% of the patients need

6

rehabilitation before follow up care. The transition of patients between services can be added to a flowchart model, which visualizes the user service journey (See the additional file 1 [21]).

Table 6-1 Specification of the components of the generic model for hip OA

Generic entities **Level 1**	Level 2	**Hip OA specified demand**	
Demand	Demand location	Regions, urban areas, rural areas.	
	Demand segments	Primary hip treatment	
	Hip OA service users	Age, gender, education, body mass index (BMI), time since surgery, previous surgery	
Services	Service elements	GP visit Referral to Special care X-ray visit Lab test	Specialist (orthopaedic surgeon) visit Conservative care Preoperative visit
	Services	Diagnosis Conservative Care Operative Care	Rehabilitation Follow-up Referral for complications
	Service journey/service user journey	Diagnosis, Conservative care, Operative care, Rehabilitation, Follow-up, Referral for complications	
Behaviour	Non-service related behaviour	Smoking, alcohol consumption, physical exercise	
	Service co–creation behaviour	Adherence to the hip OA treatment: adherence to specific instructions , adherence to specific exercises, and adherence to special therapies.	
Outcomes	Health outcomes	Reoperation, reposition, and infection Pain and impaired usual activity EQ-5D health related quality of life in relation to mobility, self-care, usual activity, pain/discomfort, anxiety/depression Evaluation of health status in comparison with best and worst imaginable health status (Visual analogue scale of EQ-5D (VAS of EQ-5D)) Satisfaction with health status	
	Service outcomes	Perceived service quality: tangibles, timeliness, responsiveness, empathy, caring, and communication Evaluation of service quality in comparison with best and worst imaginable health services Satisfaction with service	

Next, the Hip OA model describes the entity structure. A relevant dimension of structure considers the resources. For the hip osteoarthritis case, three basic classes of resources are defined as human resources, facilities, and devices. Resources per service are elaborated in the paper appendix.

The other two components of the generic model are behaviour and outcomes. Health behaviour is defined by non-service related behaviour and service co-creation behaviour. Non-service related behaviour concerns smoking, alcohol consumption, and physical exercise [24]. Co-creation behaviour concerns adherence to care (i.e. adherence to recommendations on resting, special exercises, and special therapy). The outcomes are distinguished into health outcomes and service outcomes. Health outcomes can further be distinguished into disease-specific and general outcomes. Disease specific health outcomes include pain and impairment which are assessed using a modified version of the Western Ontario and McMasters Universities Osteoarthritis Index (WOMAC) [25]. Disease specific outcomes also include complications after surgery (reoperation, reposition, and infection). Moreover, the Hip OA model defines the perception and evaluation of the health status as general health outcomes. General health outcomes are assessed using EuroQol EQ-5D, visual analogue scale of EQ-5D, and overall satisfaction with health state. Service outcomes consider perception of service quality using a short form of ServQual [26] and overall satisfaction with services (Table 6-1).

Table 6-2 Services and service journey

Service no.	Service	Service elements and precedence	Follow-up services	Follow-up rate (%)*
S1	Diagnosis	SE1 → SE2 → SE3, SE5	S2	25
			S3	75
S2	Conservative Care	SE6, SE15, SE22, SE5	S3	5
S3	Operative Care	SE7→SE17, SE16, SE18→SE8→SE19→SE4→SE9, SE10, E11→SE3	S4	95
			S5	100
S4	Rehabilitation	SE12, SE20, SE21, SE23, SE24	S5	100
S5	Follow-up	SE13	S6	1
			End of Journey	99
S6	Referral for complications	SE15, SE3	S3	1
			S5	99

*The rate of follow up services after diagnosis adds up to 100.

Case Instances

We next define instances of the Hip OA model which concern five European regions: Keski–Suomi (Finland), Larisa (Greece), Tilburg (The Netherlands), Valencia (Spain), and South-West London (UK).

By specifying the regional values for each entity of the Hip OA model instances are defined. The Managed Outcomes project did not provide a hip osteoarthritis case study in Germany. For the analyses performed in this paper we could not make use of the instance data of Valencia (Spain) due to the limited number of returned questionnaires and the instance data of South West London (UK) due to the use of different instruments. Selection of case instance countries and regions was not at random but mostly done in advance by the Managed Outcomes project. The selection of regions has however not been based on their reputation for being innovative, evidence based, etc., but mostly because of practical arguments such as data availability and provider cooperation.

Data collection

Most of the values for the network instances are collected from medical information system or surveys in the years 2011-2012. A further description of network instances can be found in the additional file 1 [21].

Table 6-3 Overview of the Hip OA regional provider networks included in the analysis

	Keski-Suomi (FI)	Larisa (GR)	Tilburg (NL)	Total
Population	269646	730115	404775	1404536
Number of operations	444	103	302	849
Operations per (10000)	16.5	1.4	7.5	6.1
Investigated institutions	1	1	1	3
Questionnaires distributed	246	166	499	911
Questionnaires returned or provided respectively	154	62	294	510
Response rate (%)	62.6	37.4	58.9	53.0
Questionnaires included	146	59	278	483

The data defining the hip OA networks, i.e. the network instances, have also been collected by interviewing. In each of the regions the data were uniformly collected using a standardized spreadsheet format to instantiate services and structure. The Hip OA model provides a comprehensive set of variables for hip OA provider networks. The description of instances can be found in the additional file 1 [21]. Data for some operational variables is collected by a patient survey. Behaviour data is collected only by survey. Most outcome data comes also from the survey. In Table 6-4 we present the model components for which we managed to successfully collect data.

Demand characteristics specifying age, gender, education, and time since last surgery were collected via the survey. Percentage of patients with complications (reoperation, reposition, and infection) was collected from provider information systems, and based on one year (2010 or 2011). The hip OA specific health state was assessed using a modified version of Western Ontario and McMasters Universities Osteoarthritis Index (WOMAC) [25]. The general health state perception was measured using the EuroQol five-item instrument [27]. To measure perception of service quality we relied on a short, generic version of the ServQual instrument [26]. This instrument concerns six aspects of quality: tangibles, timeliness, responsiveness, empathy, caring and communication. A single question in scale from extremely dissatisfied (score of 1) to extremely satisfied (score of 7) was used to measure global satisfaction with services. The patient survey also contained data on the perceived aspects of operations: traveling time and distance from home to hospital and rehabilitation institution. Patients are asked about waiting time from decision to surgery, waiting time from surgery to rehabilitation, the length of stay in rehabilitation centre, and waiting time to get a rehabilitation place (see Table 6-4). Questionnaires were also culturally adapted for the local contexts. The questionnaire was translated to region languages according to Sperber [28]. In a first step the questionnaire was translated from English to the native languages of the regions. Two native speakers of each region translated it from English and one native English speaker translated it from a region's language to English [28].

Table 6-4 Operations, behaviour, and outcomes

Operations	Behaviour	Health state/quality of life
Frequency of services [1]	Alcohol consumption [2]	Complications [1]
Frequency of service elements per service [1]	Smoking [2]	EQ-5D-utility according to Dolan (s)
Duration of service (m)	Physical exercises [2]	Services Satisfaction [2]
Duration of service elements per service [1]	Adherence to specific instructions [2]	Pain before-after surgery [2]
Resource type [1]	Adherence to specific exercises [2]	Impaired usual activities before-after surgery [2]
Amount of services in hours of care (frequency x duration) [1]	Adherence to special therapies [2]	Pain before-after rehabilitation (s)
Amount of service elements per service [1]		Impaired usual activities before-after rehabilitation [2]
Waiting time from decision to surgery [12]		
Length of stay in hospital for surgery		
Physical distance from home to hospital [12]		
Traveling time from home to hospital [12]		
Referral for rehabilitation [12]		
Waiting time for rehabilitation (days) [12]		
Length of stay in rehabilitation institution [12]		
Physical distance from home to rehabilitation institution [2]		
Traveling time from home to rehabilitation institution [2]		
Costs of service element, service journey, and service user journey [1]		
Operational service quality [2]		

[1] = operational model, [2] = survey

The study was approved in each country. The Keski Suomi study was approved by the Ethics Committee of the Central Finland Health Care District, the Larissa study was approved by the Scientific Committee of the hospital in Larissa, the Tilburg study was approved by the Ethics Committee of the St. Elisabeth hospital, the Valencia study was approved by the Hospital La Fe Ethical Committee and the South-West London study was approved by the NHS National Research Ethics Service. Permission for use of data was received from the Ethics Committee of the Central Finland Health Care District (statistical data at aggregate level), the Scientific Committee of the hospital in Larissa (statistical data and access to patient records), the Ethics Committee of the St. Elisabeth Hospital (statistical data at aggregate level), the Hospital La Fe Ethical Committee (statistical data at aggregate level) and the NHS National Research Ethics Service (statistical data and access of patient records).

All personal identifiers were removed or disguised so the person(s) were not identifiable and could not be identified through the provided text on the open questions. All participants received a letter with research information and an invitation to fill in the questionnaire. A convenient sample of institutions per network (e.g. health centre or general practitioner office) was chosen to participate in the survey. The questionnaire was provided to patients by hospitals where patients were operated. In total 911 patients were surveyed in the three regions, which resulted in a 53.0% response rate and 483 usable questionnaires (See Table 6-3).

Analysis methods

The analysis methods to reveal relationships between operations and outcomes of hip OA provider networks follow the methodology in Mahdavi et al. [12]. The Hip OA model enables to provide the descriptions of three regional instances and the subsequent descriptive comparison; the main analysis regards understanding the relationships between operations and outcomes.

Like in our studies of diabetes networks [29] and stroke networks [30] an observational multiple case study design is used, which forms a small cohort of networks with three regions . Hence this design is more robust than the single case studies, but lacks a 'controlled' intervention and a control group, thus making it weaker in attributing differences in outcomes to differences in operations. The research design has been argued to contribute to advancing evidence based operations management in health service provider networks [12]. It collects data for hip OA networks in three European countries, and subsequently analyses the data, in a standardized manner.

The methodology proposed in Mahdavi et al. [12] rests on two basic steps. In step 1 it systematically explores notable differences in outcomes between the regional instances and explores their interrelationships with notable differences in operations. The analysis explores relationships between operational variables and outcome variable based on theory, scientific evidence, and expert opinion. In step 2 systematic analysis is performed in the opposite direction: it considers notable differences in operations and explores the interrelationships with notable differences in outcomes. Again the selection of variables is based on theory, evidence, and expert opinion. Whenever possible, a notable difference refers to a statistically significant difference. A list of relevant operations and outcomes variables is given in Table 6-4.

A main concern in the analysis using the two-step method is the limited power to address differences between regions as we have samples with large size in only three regions. This may restrict the subsequent exploration of operational variables or effects of operations. To identify notable differences in both outcomes and operations we rely on one way analysis of variance (one-way ANOVA) when possible [31]. Hypothesis testing mostly relies on hierarchical regression models. Statistical analyses are performed using the IBM SPSS statistical package version 20.

Results

The results of this study consider the analysis of operations and outcomes for the population of hip OA patients in the regions according to the aforementioned two-step approach. The (differences in) operations are considered using operational models from three case instance regions, the majority of outcomes is derived from the survey with 483 included questionnaires in the analyses as not all returned questionnaires could be used because the language of questionnaire was not the native language of respondents or participants have insufficient language proficiency to answer the questions.

In the selection of data to present we rely on evidence of a) systematic reviews [13], b) empirical research, and c) expert choices. The data set supporting the results of this article is included within the article and its additional file [21].

From differences in outcomes to differences in operations

Table 6-5 presents data for selected outcome variables from three regions in the Managed Outcomes project. The major complaints of hip OA patients are pain and impaired usual activity. As a first step we consider these outcomes and explore how they have been affected by service operations in the course of time from decision for surgery to the moment of surgery and then from the moment of surgery to the time of survey. Pain and impaired usual activity are measured at three points in time. The first time point is at the time of decision for surgery, the second time point is just before the surgery, and the third is after surgery at the time of survey. Subsequently, we consider general outcomes EQ-5D health related quality of life and global satisfaction with services. These outcomes are given in Table 6-5. Furthermore, we consider post-operative clinical complications at the instance level and compare three regions (Table 6-6).

There is no significant difference between the regions with regard to pain and impaired usual activities at the time of decision for surgery. After the decision, while patients are listed for surgery, they receive conservative care until operation facilities and staff are available to realize surgeries. The level of pain and impairments just before surgery can show the effectiveness of the conservative care or pain management and if waiting time for surgery affects them (Table 6-5).

A one way ANOVA test shows that status of pain and impairments just before surgery are significantly different between the regions (Table 6-5). Such differences can be explained by length of waiting till surgery [32]. The longer the waiting time until surgery, the worse the health state and therefore the pain before surgery. We therefore hypothesize that:

H1: Pain before surgery is positively associated with waiting time from decision to surgery.

H2: Usual activity before surgery is negatively associated with waiting time from decision to surgery.

With regard to impairments at the time of survey there are also significant differences between the regions without controlling for demand characteristics. Controlled impairment at the time of survey is an indicator to compare regions with regard to effectiveness of operative and post–operative care in general. Activity of daily living may be increasingly impaired by increase in waiting time from decision to surgery [32]. However, due to the small number of participants using rehabilitation care after surgery we are not able to statistically test relationships between aspects of post-operative care and rehabilitation and impaired usual activity at the time of survey.

With regard to the overall quality of life assessed by EQ-5D, pain at the time of survey, and service satisfaction differences between regions are non-significant. This implies that final outcomes are more of less the same. The effect of the intervention doesn't appear to vary. Variation may exist in the quality of care.

Last but not least, complications after surgery are outcome measures by which operations of provider networks are compared. Data for complications is derived from provider information systems. Table 6-6 shows that the reoperation rate is the highest in Keski-Suomi. Reposition and infection rate are the highest in Tilburg.

Table 6-5 Outcomes of hip OA provider networks

		Keski-Suomi	Larisa	Tilburg	Total	F-test	df1/df2	Welch F test[e]	df1/df2
2nd time point: Pain before surgery[a]	Mean	4.15	3.58	3.76	3.86	10.96***	2/480	10.24***	2/138.0
	SD	0.94	1.36	0.86	0.98				
	N	146	59	278	483				
3rd time point: Pain last four weeks[a]	Mean	1.53	1.64	1.52	1.54	0.78	2/480	0.47	2/131.9
	SD	0.83	0.96	0.56	0.71				
	N	146	59	278	483				
2nd time point: Impaired activity before surgery[b]	Mean	4.01	4.33	3.58	3.80	22.42***	2/465	25.45***	2/152.5
	SD	1.02	0.78	0.83	0.93				
	N	141	58	269	468				
3rd time point: Impaired activity last four weeks[b]	Mean	1.66	1.93	1.91	1.84	3.66*	2/480	4.23*	2/149.6
	SD	0.81	1.10	0.96	0.94				
	N	146	59	278	483				
EQ-5D-utility according to Dolan[c]	Mean	0.82	0.76	0.81	0.81	2.60	2/469		
	SD	0.18	0.23	0.19	0.19				
	N	146	58	268	472				
Services satisfaction[d]	Mean	84.74	88.98	83.72	84.71	1.48	2/457		
	SD	20.87	17.94	22.11	21.26				
	N	142	59	259	460				

[a] The scale scored from 1 for 'no pain at all' to 5 'extreme pain.' [b] The scale scored from 1 for 'no impairment at all' to 5 ' extreme impairments.'
[c] The scale is standardised with zero for death and 1 for full health. [d] The scale scored from 0 for 'extremely dissatisfied' to 100 for 'extremely satisfied.'
[e] Due to homogeneity of variance Welch F test is reported. * p<.05, ** p<.01, ***p<.001

Table 6-6 Complications after operations

Complications (%)	Keski-Suomi	Larisa	Tilburg
Reoperations	4.1	2.9	2.0
Repositions	1.8	1.0	3.0
Infections	1.4	1.9	4.0

Based on evidence of Solomon et al. [33] and Mäkelä et al. [34] who report negative relationships between the volume of surgery per hospital and per surgeon and reoperation, reposition, and infection we hypothesize that:

H3: A higher volume of surgeries per hospital and per surgeon is negatively associated with reoperation, reposition, and infection.

Below we explore the hypotheses using mostly regression models.

The association between pain and impaired activity after surgery and waiting time

Hypothesis *H1* is tested by hierarchical regression models in Table 6-7. Step 1 controls for effects of demand characteristics age, gender, education, and pain at the time of decision for surgery on pain [35]. Time since surgery needs also to be controlled as in Keski-Suomi the survey is performed on average 16.5 months after the surgery whereas in Tilburg this was only 10.9 months after the surgery. Step 2 controls for differences between regions in which Keski-Suomi acts as reference. Step 3 takes waiting time until surgery into analysis.

Among demand characteristics gender and pain at decision for surgery significantly contribute to explain variance in pain (step 1 Table 6-7). Effects of quality of life including pain is also shown by Rolfson et al. [36]. Female patients have more pain than men. More pain at decision of surgery also increases the pain just before surgery. After controlling for age, gender, education, time since surgery, and pain at decision of surgery in step 2, differences between the networks are still statistically significant. This analysis implies a similar effectiveness for conservative care in Tilburg and Keski-Suomi. In contrast, patients in Larisa have less pain than the two other regions. The analysis in step 3 shows the small but adverse effect of waiting time on pain and therefore confirms *H1*. This analysis indicates that the longer the waiting time from decision to surgery the more the pain before surgery.

We applied a similar hierarchical regression analysis to analyse *H2* (Table 6-8). This analysis confirms a large contribution of demand characteristics to explain outcomes by explaining for 61% of variance in impairment. After control for effects of demand characteristics differences between regions disappear (step 2), with Keski-Suomi acting as reference. Analysis in step 3 in Table 6-8 rejects *H2* which indicates that increase in waiting time is not associated with increase in impaired usual activity.

Table 6-7 Hierarchical regression analysis of pain before surgery

	Variables	β Step 1	Step 2	Step 3
1	Constant	2.90**	3.06**	2.91**
	Age	0.00	-0.01	-0.01
	Gender[1]	-0.18*	-0.21*	-0.23*
	Education[2]	0.17	-0.01	-0.01
	Time since surgery	0.00	0.01	0.00
	Previous surgery[3]	0.11	0.13	0.13
	Pain first[4]	0.31**	0.35**	0.35**
2	Larisa		-0.72**	-0.71**
	Tilburg		0.04	0.11
	Keski-Suomi (reference)			
3	Waiting time from decision to surgery			0.01*
	ΔR^2	.20	.05	.01
	R^2	.20	.24	.25
	F change	16.71**	12.74**	5.70*
	df1	6	2	1
	df2	412	410	409

[1] 0=female, 1= male. [2] 0= minimum school leaving age, 1= more than minimum school leaving age.
[3] No operation before= 0, Have been operated= 1; [4] Pain at decision for surgery.
*p<.05; **p<.01 (two-tailed, pairwise, unstandardized coefficients).

Table 6-8 Hierarchical regression analysis of impaired usual activity just before surgery

	Variables	β Step 1	Step 2	Step 3
1	Constant	1.04**	1.15**	1.20**
	Age	0.00	0.00	0.00
	Gender[1]	-0.02	-0.03	-0.02
	Education[2]	-0.05	-0.02	-0.02
	Time since surgery	0.01*	0.01	0.01
	Previous surgery [3]	0.09	0.09	0.09
	Impaired activity before[4]	0.73**	0.72**	0.72**
2	Larisa		0.02	0.02
	Tilburg		-0.12	-0.14*
	Keski-Suomi (reference)			
3	Waiting time from decision to surgery			0.00
	ΔR^2	.61	.00	.00
	R^2	.61	.61	.61
	F change	108.58**	1.63	1.90
	df1	6	2	1
	df2	421	419	418

[1] 0=female, 1= male. [2] 0= minimum school leaving age, 1= more than minimum school leaving age.
[3] No operation before= 0, Have been operated= 1; [4] Impaired activity at decision for surgery.
* p<.05, ** p<.01, ***p<.001

Our findings regarding relationships between pain and impairments and waiting time add to conflicting evidences in this regard. While we found significant effects of waiting time on pain and non-significant effects on impairments, Kelly et al. report non-significance of waiting time on both pain and impairments and Fitzpatrick et al. report significant negative effects of waiting time on both variables.

The association between number of surgeries and complications

To test *H3* we relate the number (volume) of surgeries per hospital per year to the complication rate (the number of complications to total number of surgeries per year) (Figure 6-2) and the average number of surgeries per surgeon to the complication rate (Figure 6-3). Information for complication rate and volumes come from provider information systems.

Inspections in Figure 6-2 and Figure 6-3 contradict *H3* and evidence of Solomon et al. [33].

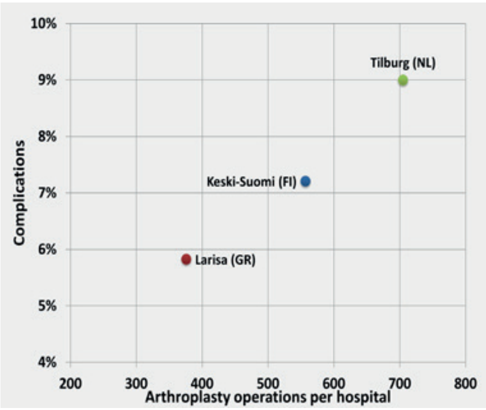

Figure 6-2 Relationship between surgeries per hospital and complication rate

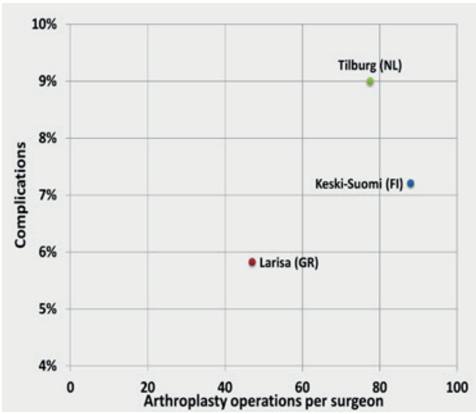

Figure 6-3 Relationship between average number of surgeries per surgeon and complication rate

From differences in operations to differences in outcomes

In response to hip OA patient demand for less pain and impairments and quality of life, provider networks deliver diagnosis, conservative care, operative, and follow up services to patients. We now consider these services and explore how differences in these services and underlying structure may affect outcomes.

Forming hypotheses to explore effects of variation of operations on outcomes is restricted to a limited set of differences, which are described below. More descriptions are provided in the additional file 1 [21].

We begin with the amount of services (hours of care) that are provided to hip OA patients in regions. We then describe the structure of services and costs of service provisioning.

Table 6-9 compares hours of care per service between regions. Hours of care are total time spent for all service elements in a service. Although statistical comparison between regions with regard to a number of hours of care per service element or service at both patient level and network level seems interesting we are unable to do so, as we have only aggregate data for three case instances and no data at patient level.

Service use for diagnosis is the highest in Keski-Suomi and the lowest in Tilburg (Table 6-9). Overall quality of life may be related to total hours of care. We therefore explore relationships between average number of hours of care per patient and EQ-5D at the time of survey taking the five dimensions of the health state including pain and impairment into account. We therefore hypothesize that:

H4: A higher number of hours of care is positively associated with EQ-5D at the time of survey.

Costs per service and total costs of the patient journey are provided in Table 6-10. The total costs of journey include spendings per patient for diagnosis, conservative care, operative care, and post-operative services. The adjusted costs by the purchasing power parity in the year 2011 vary from €5550 in Larisa to €6518 in Tilburg (Table 6-10). We may propose that more spendings will improve pain management and decrease impaired usual activity and therefore improve quality of life.

H 5: Higher costs of services are associated with a higher EQ-5D utility.

Table 6-9 Hours of care per patient

	Keski-Suomi	Larisa	Tilburg
Diagnosis	2.5	1.7	1.1
Conservative care	1.0	1.0	0.7
Operative care	278.2	385.8	147.2
Rehabilitation	96.0	8.0	1.1
Follow up	1.0	3.5	0.3
Referral for complications	0.8	6.7	0.5
Total	379.5	406.7	150.9

Most costs of hip replacement are naturally related to surgery in operating rooms and the stay at the ward except in Larisa. In contrast to the cost of other resources, the cost of an implant in Larisa is very high (Table 6-10).

With regard to the service quality dimension described by ServQual we found differences between regions using one way ANOVA (Table 6-11). These differences concern timeliness, caring, and communication. The highest values for all three belong to Keski-Suomi. The value for caring and communication is the lowest in Larisa.

Based on the Service Quality Gap Model [37] and the modification of this model for health services [26], differences in the dimensions of service quality may affect satisfaction with services. We therefore hypothesize that:

H6: Higher timeliness, caring, and communication is positively associated with a higher satisfaction with services.

Table 6-10 Costs per service and cost item (adjusted by PPP 2011)

Service dimensions	Keski-Suomi	Larisa	Tilburg
Costs of service journey			
Diagnosis (S1)	129	213	161
Conservative care (S2)	24	16	972
Operative care (S3)	5212	4809	4765
Rehabilitation (S4)	686	50	492
Follow up (S5)	84	172	10
Referral for complications (S6)	82	341	118
Total	6218	5550	6518
Costs per cost items			
Outpatient	195	156	301
Surgery	2228	1231	2943
Ward	2199	1945	1841
Implant	1072	2285	1212

We furthermore hypothesize that according Conner-Spady et al. [38] to waiting time to receive services negatively affects service satisfaction.

H7: Longer waiting time from decision to surgery and from surgery to rehabilitation is negatively associated with satisfaction with services.

Evidences also indicate that service quality may affect health related quality of life in hip OA patients [39]. We therefore hypothesize that:

H8: Service quality is positively associated with EQ-5D utility.

6

The association between service use and outcomes

Hypothesis *H4* is tested using Figure 6-4. Data for EQ-5D comes from the survey in the regions. This inspection shows that increase in service use is not associated with increased EQ-5D. This analysis therefore rejects hypothesis *H4*.

The associations between costs and outcomes

To test hypothesis *H5* we relate the costs of hip OA care to the average value of EQ-5D utility (Figure 6-5). This visual inspection cannot suggest any relationship between costs and EQ-5D at network level given the small number of cases.

Table 6-11 Comparison between regions in ServQual

Quality dimensions [1]		Keski-Suomi	Larisa	Tilburg	Total	ANOVA F-test	df1/df2	Welch F test	df1/df2
Tangibles	Mean	5.97	6.22	6.10	6.07	0.78	2/480	.78	2/160.7
	SD	1.69	1.15	1.33	1.43				
	N	146	59	278	483				
Timeliness	Mean	5.60	6.17	6.31	6.08	10.17**	2/480	7.66**	2/141.4
	SD	1.96	1.51	1.26	1.56				
	N	146	59	278	483				
Responsiveness	Mean	5.92	6.39	6.22	6.15	3.28*	2/480	2.79	2/148.5
	SD	1.57	1.35	1.25	1.37				
	N	146	59	278	483				
Empathy	Mean	6.41	6.71	6.44	6.46	1.67	2/480	2.43	2/166.2
	SD	1.26	0.89	1.11	1.13				
	N	146	59	278	483				
Caring	Mean	5.88	6.63	6.19	6.15	7.00**	2/480	9.12**	2/172.7
	SD	1.54	0.95	1.28	1.35				
	N	146	59	278	483				
Communication	Mean	5.77	6.53	6.07	6.04	5.78**	2/480	6.88**	2/158.9
	SD	1.67	1.13	1.36	1.45				
	N	132	58	257	447				

[1] The least value=1 and the best value=6. Note: * p<.05, ** p<.01

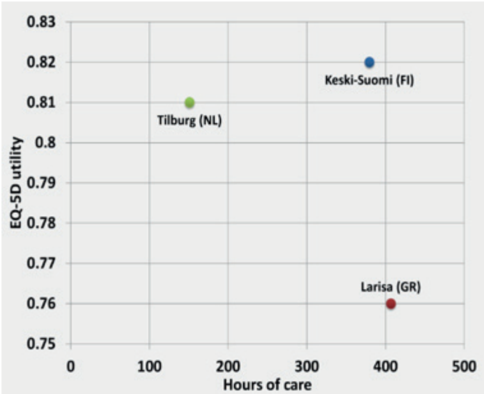

Figure 6-4 Relationship between service use and EQ-5D

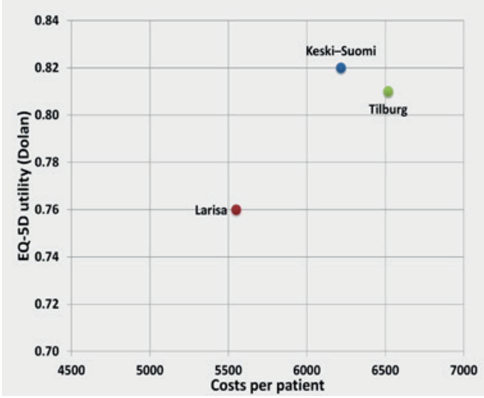

Figure 6-5 Relationship between average costs of service (PPP for 2011) and EQ-5D utility score

The association between service quality and service satisfaction

Hypotheses *H6* and *H7* are tested using the hierarchical regression models in Table 6-12. A basic set of demand variables in step 1 in Table 6-12 explains for 2% of the variance. In this step we control for age, gender, education, and time since last surgery. Step 2 controls for differences between regions. In addition, in step 3 we control for effects of pain and impairments at the time of survey as these variables are predictors of service satisfaction [36].

6

To explore effects of service quality on outcomes we first analyse *H7* and then *H6*. The analysis in step 4 shows non-significant effects of waiting times on satisfaction and therefore rejects *H7*. The analysis in step 5 shows that the ServQual dimensions significantly increase the explained variance in service satisfaction by 27%. Therefore, this analysis confirms *H6*.

This last regression model explains a total of 33% of variance in service satisfaction. In comparison with other case studies in the Managed Outcomes, the model of service satisfaction for the hip osteoarthritis case accounts for a much smaller amount of variance in service satisfaction. Regression models in diabetes [29] and stroke cases [30] explain for 43% and 59% of variances in service satisfaction respectively.

In this last step impaired usual activity is the only demand and health state variable that has a negative significant effect on service satisfaction. However, previous studies show conflicting results regarding relationships between aspects of health status and service satisfaction. A study by Rolfson et al. [36] reports that health state is an important predictor of service satisfaction, whereas Baumann et al. show non-significant effects of health state [40]. Reported evidences by Sinici et al. [41] lend support on non-significant effects of other demand characteristics (age, gender, and education) on satisfaction with services.

Table 6-12 Hierarchical regression analysis of relationships between service quality and service satisfaction

	Variables	B Step 1	Step 2	Step 3	Step 4	Step 5
1	Age	-0.21*	-0.19*	-0.19*	-0.16	-0.14
	Gender[1]	1.83	1.96	1.96	2.37	2.29
	Education[2]	-5.10*	-3.90	-3.95	-3.97	-3.59
	Time since surgery	-0.18	-0.27	-0.34*	-0.32*	-0.22
2	Larisa		3.15	4.27	4.68	-0.27
	Tilburg		-1.61	-1.13	-2.03	-4.14*
	Keski-Suomi (reference)					
3	Impaired usual activity at time of survey			-3.55**	-3.58**	-2.66**
	Pain at the time of survey			-0.66	-0.96	0.35
4	Weeks from decision to surgery				-0.13	-0.02
	Days waiting for rehabilitation				0.17	0.06
5	Tangibles,					3.45**
	Timeliness					1.02
	Responsiveness					3.91**
	Empathy					-3.53**
	Caring					2.89**
	Communication					4.58**
	ΔR^2		.01	.02	.01	.27
	R^2	.02	.03	.05	.06	.33
	F change	2.60	.98	7.38**	2.27	36.49***
	df1	4	2	2	2	6
	df2	478	476	474	472	467

[1] 0=female, 1= male. [2] 0= minimum school leaving age, 1= more than minimum school leaving age.
[3] No operation before= 0, Have been operated= 1.
* p<.05, ** p<.01, *** p<.001, two-tailed, pairwise, unstandardized coefficients.

The ServQual dimensions tangibles, responsiveness, caring, and communication have significantly positive effects on service satisfaction. Communication has the largest contribution. The dimension empathy makes a significant negative contribution to the model. This analysis also notifies non-significant effects of timeliness on satisfaction with services regardless of its significant differences between regions. In the diabetes case of the Managed Outcomes project, timeliness, empathy, and communication are found non-significant and in stroke case timeliness, empathy, caring, and communication are non-significant determinants of satisfaction with services. However, these variables are suggested by Bowers et al. [26] as generic determinants of service satisfaction.

The association between service quality and quality of life

Hypothesis *H8* is tested using a regression analysis in 6 steps in Table 6-13. In step 1 of the analysis, demand characteristics are controlled. Step 2 controls for differences between regions taking Tilburg as a reference. Waiting time, length of hospital stay, and service satisfaction are controlled in steps 3-5. In step 6 effects of quality of care on EQ-5D utility are tested.

Analysis in Table 6-13 shows that education is the only demand variable that significantly affects EQ-5D. The analysis in step 2 shows that there is no difference between regions. Waiting time is also a non-significant predictor of quality of life.

Table 6-13 Hierarchical regression analysis of relations between quality of care and EQ-5D utility

	Variables	β Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
1	Age	.000	.000	.000	.000	.000	.000
	Gender	.035	.030	.032	.036	.030	.031
	Education	.051*	.038	.038	.023	.031	.028
	Time since surgery (month)	.002	.002	.002	.002	.003	.002
	Previous surgery	.020	.020	.020	.010	.005	.015
2	Keski-Suomi		.019	.026	.034	.030	.039
	Larisa		-.045	-.041	-.035	-.050	-.046
	Tilburg (reference region)						
3	Waiting time till surgery			-.001	-.001	-.001	.000
4	Length of hospital stay				-.005**	-.004**	-.004*
5	Services satisfaction					.002**	.002**
6	Tangibles						.002
	Reliability						.018*
	Responsiveness						.022
	Empathy						.014
	Caring						-.002
	Communication						-.027*
	ΔR^2	.03	.01	.00	.06	.05	.04
	R^2	.03	.04	.04	.10	.14	.19
	F change	2.09	1.63	.81	21.63***	20.44***	3.06**
	df1	5	2	1	1	1	6
	df2	357	355	354	353	352	346

[1] 0=female, 1= male. [2] 0= minimum school leaving age, 1= more than minimum school leaving age.
[3] No operation before= 0, Have been operated= 1.
* p<.05, ** p<.01, *** p<.001, two-tailed, pairwise, unstandardized coefficients.

A regression model in step 3, containing demand, region, and waiting time variables, accounts for 4% of variance in quality of life. Adding length of hospital stay to this regression model increases the explained variance by 6%. Service satisfaction also adds 5% to the explained variance, which is significant. This lends support to evidences of relationships between service satisfaction and quality of life [42]. A regression model in step 6 that includes ServQual dimensions, in addition to the variables in the previous models, accounts for 19% of explained variance in EQ-5D utility of which 4% is attributed to ServQual dimensions. Among these dimensions, timeliness and communication are significant predictors of health related quality of life.

Discussion

This study explores the associations between operations and outcomes in order to develop an evidence base for the management of hip OA service provider networks. The present study is one of the several studies in the EU funded Managed Outcomes project to advance understanding on effects that health service operations have on outcomes. Alike other case studies in the Managed Outcomes, the operational description and analysis of operations-outcomes relationships in this study relies on the modelling and analysis methodology in Mahdavi et al. [29].

Outcomes of hip OA provider networks considered are pain, impairments, EQ-5D utility, and satisfaction with services. We managed to explain for 25% of variance in pain just before surgery. Almost all explained variance in this outcome is attributed to demand and context. Furthermore we noticed that a longer waiting time from decision to surgery leads to an increase in pain. We also explained for 61% of variance in impairments just after surgery, almost all of which is attributed to demand characteristics. Waiting time doesn't have a significant effect on this outcome. A regression model of EQ-5D explains 19% of variance in this outcome, of which 15% is attributed to operations. Of service quality dimensions, communication with providers has a negative effect on EQ-5D utility. These findings reveal modest results regarding the relationships between operations and health outcomes.

A total of 33% of variance in satisfaction with services is explained by operations and behaviour. Only 6% of this variance is attributed to demand characteristics and (context) of regions of which impairments makes patients more dissatisfied than pain. Alike other cases in the Managed Outcomes, ServQual dimensions account for the most of the variance explained by the regression model, largely by communication and responsiveness. The non-significant effect of timeliness and negative significant effect of empathy threaten the validity of the modified ServQual to hip OA service operations [26].

In contrast to other case studies of the Managed Outcomes considering Type 2 Diabetes and Stroke, this study provides only few evidences to enhance our understanding regarding operations-outcomes relations. In the Diabetes and Stroke case studies of the Managed Outcomes project we managed to explain a larger amount of variance in quality of life/health state than in this case study. With regard to service satisfaction, differences are larger as 41% of variance of this outcome in diabetes case study and 46% in stroke case are explained by operations in comparison with 28% in hip case study. Such differences in the explained variances in outcomes between this case study and other case studies of the Managed Outcomes project suggest that determinants of satisfaction are disease specific, and appear to confirm the importance of disease specific operational models.

This study has some limitations and strengths. Missing data on adherence to care led to exclusion of three adherence variables in our analysis. Another limitation regards the limited number of case instances for the analysis. Within the regions that we analysed very limited data for rehabilitation service was available. The cohorts of patients come from a non-random selection process. Strength of the study lies in the fact that for the first time a generic template was used to describe aspects of hip OA care, which was followed by the application of methodology for analysis.

Conclusions

The Hip OA model is feasible for translation into case instances as it provides a generic template for description of hip OA care that can be applied to different settings. The Hip OA model with case instances and detailed evidence shows how essential features of hip OA care can be captured to build an evidence base for management of a hip OA provider networks. This study therefore enhances understanding of hip OA provider network by presenting tools for description of care components beyond patient self-management and for associating health operations to outcomes. At the same time, it leaves room for identifying further determinants of outcomes, especially regarding the clinical outcomes which remain largely unexplained. Further research to advance the understanding of and evidence base for the performance of hip OA networks is therefore called for. Moreover, together with previous publications from the Managed Outcomes project regarding other diseases, further research on other diseases in relation to the presented hip OA results may advance understanding of generic and disease specific relationships between operations and outcomes in health service networks.

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Appendix

This appendix describes the operations of hip osteoarthritis (hip OA) in the provider networks studied in the Managed Outcomes project. These networks are instances of the Hip OA model. An instance is derived from the Hip OA model, which defines *Services* and underlying *Structure* that are used to meet patient *Demand* for hip OA care. In the description of these entities we focus on the most relevant subcomponents for the provider networks. We managed to successfully instantiate the Hip OA model in five regions in the European counties Finland, Greece, The Netherlands, Spain, and United Kingdom (Table 6-14). This appendix describes demand, services, and structure of the provider networks for regions in these countries.

Table 6-14 Demand characteristics of hip OA

		Finland	Greece	Netherlands	Spain	United Kingdoms
Region		Keski-Suomi	Thessalia/ Larisa	Tilburg	Valencia-La Fe	SW London
Population per age group	<60	203128		316789	157685	2004300
	60-69	32559		46368	20783	224400
	70-79	21200		27611	14627	149200
	>79	12759		14007	9526	106600
Population	Total	269646	730115	404775	202621	2484500
Frequency of Hip replacement surgery per age group	<60	118	27	53	28	233
	60-69	132	27	106	25	331
	70-79	149	44	112	28	417
	>79	45	5	31	8	292
	Total	444	103	302	89	1273
Incidence of hip replacement surgery	Incidence per <60	0.58	0.13	0.17	0.18	0.12
	Incidence per 60-69	4.05	0.83	2.29	1.20	1.48
	Incidence per 70-79	7.03	2.08	4.06	1.91	2.79
	Incidence per >79	3.53	0.39	2.21	0.84	2.74
	Incidence rate per 1000	1.65	0.14	0.75	0.44	0.51
Gender	Female	83 (58.5)	42 (73.7)	165 (61.1)	8 (53.3)	306 (61.2)
	Male	59 (41.5)	15 (26.3)	105 (38.9)	7 (46.7)	194 (38.8)
Age	Mean	68.5	67.4	69.7	64.1	69.4
	Standard-deviation	11.9	9.9	9.3	15.6	10.7
	Median	70	70	70	64	70

6

Demand

Three sub-components of the entity demand are defined in the Hip OA model. These include demand location, demand segment, and demand characteristics. Demands for hip OA care stem from high risk patients and patients who are already diagnosed with hip OA or receive conservative care, operative care, or post-operative care. Demand segment considered consists of patients who receive hip OA care.

Characteristics of hip OA patients living in the regions, frequency of hip OA surgery, and hip OA incidence rate are given in Table 6-14. SW London has the largest volume of surgery between regions. Patients in the age group 70-79 years have the highest rate of the surgery. The majority of hip OA patients in these regions are female. The highest incidence rate belongs to Keski-Suomi. Patients in Tilburg are older and in Valencia younger than other regions. Below we define service elements, services, and service journey for the demand segment defined.

Services

Service elements (SEs) provided in the five regions studied in the Managed Outcomes project are listed in Table 6-15. Tilburg stands out with SE 15-24, which are provided particularly in this region. Differences may also regard services and service user journey as presented below.

Table 6-15 Service elements used in study regions

		Keski-Suomi (FI)	Larisa (GR)	Tilburg (NL)	Valencia (SP)	SW London (UK)
SE1	First GP visit	x	x	x	x	x
SE2	Referral to Special care/ Special care	x	x	x	x	x
SE3	X-ray visit	x	x	x	x	x
SE4	Lab test	x	x	x	x	x
SE5	Specialist (orthopaedic surgeon) visit	x	x	x	x	x
SE6	Conservative care	x	x	x	x	x
SE7	Preoperative screening/preoperative visit	x	x	x	x	x
SE8	Admission for surgery	x	x	x	x	x
SE9	Surgery	x	x	x	x	x
SE10	Post-anesthesia care	x	x	x	x	x
SE11	Post-operative care	x	x	x	x	x
SE12	Post-operative rehabilitation	x	x	x	x	x
SE13	Follow-up visit	x	x	x	x	x
SE14	Referral for Complications	x	x	x	x	x
SE15	Marcaine treatment			x		
SE16	Nurse specialist visit			x		
SE17	Additional pre-operative screening			x		
SE18	Arranging nursing home or home care			x		
SE17	Additional pre-operative screening			x		
SE19	Pre-operative care			x		

Table 6-15 Service elements used in study regions (continued)

		Keski-Suomi (FI)	Larisa (GR)	Tilburg (NL)	Valencia (SP)	SW London (UK)
SE20	Discharge from hospital			x		
SE21	Rehabilitation (not in hospital)			x		
SE22	Weight loss program			x		
SE23	Care in nursing home			x		
SE24	Home care			x		

A set of service elements (Table 6-15) constitute a service. Six services are defined in the Hip OA model, which are also applied to the five regions studied. Service elements used by regions per each service show some differences, take for instance diagnosis service in which service elements and their sequences are different.

Table 6-16 Sequence of service elements in services

Services	Keski-Suomi	Larisa	Tilburg	Valencia	SW London
Diagnosis	SE1 → SE2 → SE3 → SE4 or SE4 → SE3 → SE4	SE3, SE4, SE5	SE1 → SE2 → SE3, SE5	SE1→SE2→SE3,SE4,SE5	SE1, SE2, SE3, SE4, SE5
Conservative care	SE5, SE6	SE6	SE6, SE15, SE22, SE5	SE6	SE6
Operative care	SE7→SE8→SE9→SE10	SE7, SE8, SE9, SE10, SE11	SE7→SE17, SE16, SE18→SE8→ SE19→SE4→ SE9, SE10, SE11→SE3	SE7→SE8→SE9→SE10→SE11	SE7, SE8, SE9, SE10, SE11
Rehabilitation	SE11, SE5	SE12	SE12, SE20, SE21, SE23, SE24	SE12	SE12
Follow-up	SE12, SE5	SE13	SE13	SE13	
Referral for complications	SE13	SE14	SE15, SE3	SE14	Se13, SE14

A set of services constitutes a service journey. The hip OA service journey at Keski-Suomi is illustrate in Figure 6-6. The backbone of the service journeys can be roughly the same also in the four other regions. Figure 6-6 illustrates that the journey starts with the diagnosis service during which a decision is made to operate or to provide conservative care. The percentage of patients who need operative care or conservative care after diagnosis can subsequently affect use of expensive resources and costs. From the demand side, the percentage of patients receiving operative care can be meaningfully affected by the patient's health behavior, performance of networks e.g. waiting list management, and attitude regarding pain and discomfort caused by the disease. Thereby, transition probabilities between services may vary between regions leading to different use of service elements and different health outcomes. A lower rate of operative care after diagnosis may indicate that a higher percentage of patients need to deal with pain, impaired activity, and other discomfort.

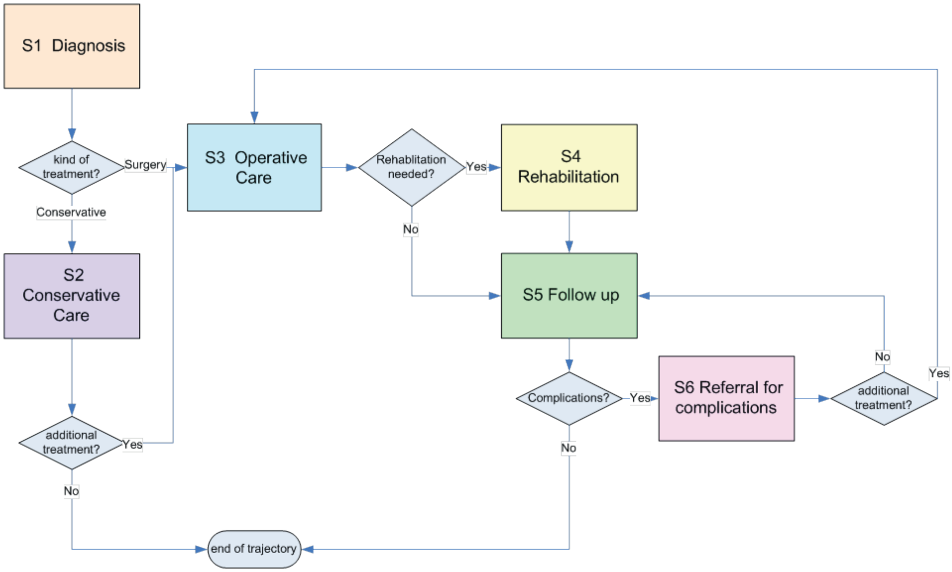

Figure 6-6 Hip OA patient journey in Keski-Suomi

Duration of service time (minutes) per service element is given in Table 6-17. Table 6-17 shows that Keski-Suomi provides the highest hours of diagnosis service per patient between regions. Larisa provides the most hours of operative service and SW London the least. The most hours of care for rehabilitation are provided at Keski-Suomi, and for the follow-up and referral for complication at Larisa.

Structure

The structure entity in provider networks constitutes service provision points (SPPs) and resources. One hospital in each region provides hip OA care in cooperation with primary care networks that refer patients for further specialized treatments. We do not further elaborate SPPs. Resources are defined based on type of resources (human resources, devices, etc.).

Most service elements are provided by use of two or more resources. Type of resources and amount of resource used per service is given in Table 6-18.

Table 6-17 Duration of service time per service element

	Service elements	Keski-Suomi (FI)	Larisa (GR)	Tilburg (NL)	Valencia (SP)	SW London (UK)
S1	First GP visit	30		15	15	10
	Referral to Special care	30			7	10
	X-ray visit	1	4	5	1	1
	Lab test	1	1		1	1
	Specialist (orthopaedic surgeon) visit	90	95	45	60	60
	Total service time (hours)	2.5	1.6	1.0	1.4	1.3
S2	Conservative care	60	60	25	17	60
	Marcaine treatment			4.5		
	Weight loss program			4.5		
	Specialist (orthopaedic surgeon) visit			5		
	Total service time (hours)	1.0	1.0	0.7	0.3	1.0
S3	Preoperative visit	100	130	15	50	
	Admission for surgery	1264	2086	50	972	220
	Surgery	1320	820	450	940	1170
	Post-anesthesia care	600	780	120	540	260
	Post-operative care	13406.6	19333.4	8085	12931.4	4761
	X-ray visit			10		
	Lab test			10		
	Pre-operative care			30		
	Additional pre-operative screening			6		
	Nurse specialist visit			30		
	Arranging nursing home/home care			13.5		
	Total service time (hours)	278.2	385.8	146.7	257.2	106.9
S4	Post-operative rehabilitation	5760	480	10	75	
	Discharge from hospital			50		
	Rehabilitation (not in hospital)			4		
	Total service time (hours)	96.0	8.0	1.1	1.3	0.0
S5	Follow-up visit	60	210	20	90	120
	Total service time (hours)	1.0	3.5	0.3	1.5	2.0
S6	Referral for complications	50	400	32	40	50
	Total service time (hours)	0.8	6.7	0.5	0.7	0.8

Table 6-18 Resource use per (pre-operative) service (minutes of care/number)

Service	Resource[1]	Keski-Suomi	Larisa	Tilburg	Valencia	SW London
S1	General practitioner/Family Physician	60		15	22	20
	X-Ray	1	4	5	1	1
	Lab	1	1		1	1
	Orthopedic Surgeon	30	30	22.5	30	30
	Outpatient clinic nurse	60	35		30	30
	Assistant physicians/Orthopedic surgeon registrar		30	22.5		
	Total use of resources[2]	2.5	1.6	1.0	1.4	1.3
S2	General practitioner/Family Physician	30			7	30
	Physiotherapists	30	30	28		30
	Orthopaedic Surgeon		30	2.5	10	
	Orthopedic surgeon registrar			7		
	Dietician			1		
	Nurse specialist			0.5		
	Total use of resources	1.0	1.0	0.7	0.3	1.0

[1]All resource except X ray and Lab are measured in minutes.[2] Total resource use per service is measured in hours of care. Lab test and X-ray are not included in estimating total resource use.

As shown in Table 6-18, there exist large differences between regions in the use of resources per service. In diagnosis service, the use of nurse and assistant physicians/orthopedic surgeon registrar is different between regions. For diagnosis in Larisa patients directly go to specialists; whereas, in the other regions GPs/family doctors initiate the journey and refer patients to specialists.

With regard to conservative care, Keski-Suomi, Valencia, and SW London GPs/family doctors together with physiotherapist take care of patients; whereas, in three other regions GPs/family doctors together with orthopedic surgeons do so. Tilburg is the only region that uses nurse specialist and dietician in conservative care.

Table 6-19 shows use of resources for operative care service (S3).

Table 6-19 Resource use per (operative) service (minutes of care/number)

Service	Resource	Keski-Suomi	Larisa	Tilburg	Valencia	SW London
S3	Orthopaedic Surgeon	240	120	100	295	90
	Outpatient clinic nurse	30	30		15	
	Anaesthesiologists/ Anaesthetists	330	270	120	400	200
	Physiotherapists	90	60	10		120
	Lab	1	4		1	1
	X-Ray	1	2	5	1	3
	Assistant physicians		1592.4			
	Nurse practitioner			21		
	Beds (surgery/orthopedic)	8640	12960	7200	10224	4440
	Ward nurses	5889.6	6912	885	3578.4	330
	Operating rooms/ Theatres	180	180	120	200	180

Table 6-19 Resource use per (operative) service (minutes of care/number) (continued)

Service	Resource	Keski-Suomi	Larisa	Tilburg	Valencia	SW London
	(surgery/orthopedic)					
	Implant	1	1	1	1	1
	PACU Beds	240	300	120	180	120
	PACU nurses	240	360	60	180	120
	X-ray technician			5		
	Lab nurse			10		
	Nurse specialist			43.5		
	Drainage device / blood self infusion		1			
	OR/theater nurse	810	360	120	360	810
Total use of resources		278.2	385.8	146.8	257.2	106.9

Various resources are used in operative care services. The most notable differences in the use of resource for S3 (Table 6-19) regard the nursing service and time duration for use of beds (surgery/orthopedic).

Table 6-20 Resource use per (post-operative) service (minutes of care/number)

Services	Resource	Keski-Suomi	Larisa	Tilburg	Valencia	SW London
S4	Beds (rehabilitation hospital)	5760	480			
	Physiotherapists			14	75	
	Ward nurses			30		
	Orthopedic surgeon registrar			10		
	Pharmacy assistant			10		
	Physiotherapists			14	75	
	Total use of resources	96.0	8.0	1.1	1.3	0.0
S5	Orthopaedic Surgeon	60	60	10	45	60
	Outpatient clinic nurse		60		45	60
	X-Ray	1	3		3	3
	Assistant physicians /Orthopedic surgeon registrar		90	10		
	Total use of resources	1.0	3.5	0.3	1.5	2.0
S6	Orthopaedic Surgeon	30	120	15	20	30
	Outpatient clinic nurse/Outpatient practice assistant	20	80	2	20	20
	X-Ray	1	4	4	1	1
	Lab	1	4		1	1
	Assistant physicians/Orthopedic surgeon registrar		200	15		
	Total use of resources	0.8	6.7	0.5	0.7	0.8

Tilburg uses a multidisciplinary team with a broad range of professionals for rehabilitation care. In all services, orthopedic surgeons have a key role to play.

Table 6-20 shows resource use in rehabilitation, follow-up, and referral for complication.

Costs

Cost per service element and services are given in Table 6-21. These cost data are adjusted by the purchasing power parity (PPP) for year 2011 and therefore can be used for comparisons between regions. Amount of resource use per service element and unit cost of resource trigger differences in costs between regions.

Table 6-21 Costs of service elements (adjusted by PPP year 2011)

Services	Service elements	Keski-Suomi	Larisa	Tilburg	Valencia	SW London
S1	First GP visit	18		10	8	9
	Referral to Special care	18			4	9
	X-ray visit	32	166	130	24	35
	Lab test	24	31		69	27
	Specialist (orthopaedic surgeon) visit	38	15	22	30	36
	Total	129	213	161	133	116
S2	Conservative care	25	15	866	10	34
	Weight loss program			104		
	Specialist (orthopaedic surgeon) visit			2		
	Total	25	15	972	10	34
S3	Preoperative visit	72	92	4	96	62
	Admission for surgery	205	159	363	335	50
	Surgery	2645	2689	2084	1903	2656
	Post-anesthesia care	383	400	27	334	175
	Post-operative care	1908	1469	2146	4511	435
	X-ray visit			130		35
	Pre-operative care			7		
	Additional pre-operative screening			1		
	Preoperative screening			4		
	Total	5212	4809	4766	7179	3415
S4	Post-operative rehabilitation	686		346	27	
	Discharge from hospital			7		
	Rehabilitation (not in hospital)			139		
	Total	686		492	27	
S5	Follow-up visit	84	173	10	117	179
S6	Referral for complications	82	341	118	105	91
Total costs of service journey		6218	5550	6518	7572	3836

The highest cost of diagnosis service is observed in Larisa, conservative care in Tilburg, operative care in Valencia, and rehabilitation in Keski-Suomi. Total costs of service journey are the highest in Valencia. Among cost items, surgery is the most expensive service element. The second most expensive service element is post-operative care.

The differences described in this appendix along with evidence bases in the article provide a ground to further hypothesize relationships between components of operations and health outcomes.

Chapter 7

General Discussion

Introduction

The overall aim of this thesis is to advance understanding of relationships between health service operations and outcomes in health service provider networks in order to create an evidence base for health service operations management in disease-focused provider networks. Following the establishment of evidence-based medicine, evidence-based management is gaining acceptance in health services [1]. The management of health service provider networks is mostly studied from an organizational science perspective [2, 3], investigating for instance the coordination among providers. Though the Donabedian's model of Structure-Process-Outcome (SPO) dates from the sixties [4], the relationship between outcomes on the one hand and the operational structures and processes of provider networks on the other hand have however received little attention. Of the hundreds of operational modelling studies in health services, few models embrace the required components for operations-outcomes analyses; in particular outcomes are missing in nearly all studies [5]. Operations of provider networks have been rarely considered as a unit of analysis in contrast to operations of departmental or single providers [6, 7]. Moreover, evidence of reuseability of models and therefore the generalizability and external validity of the models are unclear. Indeed, it has been observed that the evidence base for evidence based management in provider networks is in an early stage [8]. Consequently, the effects on outcomes of services and the structures supporting them remain by and large to be understood.

While outcomes are well-conceptualized [9] and extensively researched, the relationships with operations remain under-researched. In fact, systematic description of operations is often lacking in health services researches. This holds particularly true for more complex settings such as provider networks. By consequence, there is lack of evidence regarding the relation between operations and outcomes for provider networks [10]. The creation of an evidence base is also hindered by research design challenges, e.g. infeasibility of recruiting larger samples of provider networks. Give the increasing importance of the performance of provider networks to address contemporary health service needs, for instance for age and life style related conditions, there is a need for systematic modelling and analysis to advance the evidence base for provider networks. This research aims to contribute to this modelling, analysis, and advancement. With this PhD research we also aim to bridge the gaps between health operations management research, which often fails to systematically address outcomes, and health service research, which tends not to systematically address operations.

This chapter first discusses the main findings. Subsequently, it addresses the theory and methodology of the current study. Finally, the implications of this research for practice as well as recommendations for future research are addressed.

Main findings

The main empirical findings are chapter specific and were summarized within the respective chapters. While addressing the findings of the research we synthesize these empirical findings as required to answer the research questions presented in Chapter 1.

Question 1: Which models exist for health service operations, what are the purposes of these models, the application areas, the modelling methods, and achievements?

The majority of operational models use descriptive modelling techniques. With few exceptions however, the studies do not regard networks but instead focus on organisations or departments. Furthermore, only few models consider chronic and life style diseases, and hence there has been little interest in the complex and long term demands associated with many of today's most prevalent diseases and the health service operations of the networks servicing these demands.

Our literature review also revealed that reuse of previous results from generically oriented operational modelling studies is quite limited. The majority of the studies are not evidence-based and rely at best in a general sense on empirical results as only 2% of the included studies report use of previous empirical results. However, 23% of the studies report use of theoretical results. With regard to implementation, only 15% of the studies report the application of models and solutions to real practice problems and 6% of the studies report implementation and evaluation of effects on practices.

Question 2: What understanding and evidence have existing models for health service operations delivered regarding patient outcomes?

Although the main purpose of operational models in health care should be to improve patient outcomes [11], outcomes either in the form of health state, quality of life, or experiences and satisfaction are hardly explicitly considered in the existing operational models. Most models set out to improve efficiency and care process aspects for which the relationships with outcomes remain unclear.

The review study on operational modelling in health care provided an evidence base regarding the application of operational models. As a result of the review, we present in Chapter 2 a synthesis, which considers the purpose of models, the application areas of models, the modelling methods, and the results achieved [12] particularly regarding implementation and outcomes. The synthesis may assist future researchers and practitioners to build on the achievements of previous researchers.

Questions 3: Which components of health service operations are generically appropriate to be included in the models to advance the evidence base, in particular with regard to the validity of relationships between operations and outcomes in regional provider networks?

Given the lack of a generic model for operational modelling of health service operations in provider networks a new framework is developed to be applied in empirical research. Donabedian's SPO model has served as a basis for the proposed model. Two extensions are made to the original SPO model, making use of design sciences [13] and service management science [14]. Donabedian defines in his SPO model three major entities *Structure*, *Process* and *Outcomes*. The CIMO logic, as for instance considered in design sciences, considers Intervention in its Context and emphasizes Mechanisms by which both intervention and structure create Outcomes [13]. Based on this theory the entity *Demand* is added to the model to capture patient and population related contextual factors which are known to correlate with outcomes. Demand captures patient data, as well as relevant demographic information, and enables to distinguish patient populations as is relevant for the service operations and outcomes. Considering the service nature of healthcare, co-creation by the user is included in the model through the entity *Behaviour* in order to present the role of patients in healthcare interventions. The resulting generic model presents five entities as central components in health service provider networks. These entities are *Demand, Services, Structure, Behaviour and Outcomes*.

Question 4: How can the generic model be adjusted to derive disease specific models (specification) and to characterize corresponding regional health service networks (instantiation) with disease specific and regional contextual detail?

The developed framework takes the generic model as a basis, and enables to derive disease-specific models through specification, by adjusting and extending the general model. The actual descriptions of disease specific provider networks take place in two instances: a region instance which in addition to structure and service data, includes aggregate data regarding health service users, and health service user instances which capture the relevant data values for individual health service users.

Question 5: How does the generic modelling framework facilitate descriptions and analyses of provider networks of different diseases (type 2 diabetes (T2D), Stroke, and Hip OA) or different types of provider networks?

The framework distinguishes generic and specific features of demand, structures, services, behaviour, and outcomes. The generic model consists of generic, standardized, dimensions of demand, services, structure, behaviour, and outcomes. Based on this generic core, each of the developed models for T2D, stroke, and hip OA provides disease specific dimensions. The descriptions and analysis in the research question are subsequently provided in the form of instances of the disease specific models, created for regional provider networks for the diseases in six European countries.

Table 7-1 below provides insight in the value of specification, in terms of additional explained variance in outcomes by demand, structures, services and behaviour. The right-most column presents the total explained variance by the disease specific models for main outcome dimensions. Next, the columns labelled ‘generic’, respectively ‘specific’, present the explained variance for models which only contain generic, respectively specific dimensions. The value in the latter column is as an upper bound for the explained variance by specification. The difference between the overall explained variance, and the generically explained variance serves as a lower bound. We may conclude from the difference between of the upper and lower bounds that the correlations exist between the presently modelled generic and specific dimensions.

Table 7-1 Outcome variance explained by generic and specific components

Disease		Components	Generic	Specific	Total
T2D	Generic	EQ-5D	17-18%	12-13%	22-25%
		Satisfaction	38-41 %	17-18%	42-45%
Stroke	Generic	EQ-5D	13-15 %	40-41%	42-45%
		Satisfaction	34-36%	13-15%	36-39%
	Specific	mRS	13-14%	16-18 %	26-30%
Hip OA	Generic	EQ-5D	9%	11%	17%
		Satisfaction	32%	1%	34%
	Specific	Impairments	2%	8%	9%

As may be expected, we observe that the disease specific demand, structure, services, and behaviour dimensions explain the majority of variance of the disease specific clinical outcomes mRS and impairments presented above. For the generic health outcome, EQ5D, the picture is mixed. For T2D the specific dimensions explain at most half the variance, whereas for stroke they can explain almost all of the variance. Hip OA is in between. For the clinical and health outcomes, we can therefore conclude that the specification increases the understanding in the relationship between operations and outcomes. For satisfaction with services, on the other hand, we observe from Table 7.1 that the total explained variance can by and large be explained by the generic dimensions only. This raises the question whether specific dimensions have little impact on satisfaction or have not yet been identified and included in the models (despite the presently evidence based selections).

Question 6: Does analysis of the instances and models advance the evidence base on health service operations in regional provider networks for T2D, stroke, and hip OA?

We investigated for the three aforementioned conditions, the relationships between operations and outcomes in health service provider networks using a multiple case study. The models and analyses can partly explain the variance in the outcomes between regions. The differences in outcomes turn out to be indeed associated with differences in operations (See Table 7-2).

Of course, the amount of explained variance varies among outcomes as well as between the diseases (See Table 7-2). The amount of explained variance in Table 7-1 and Table 7-2 are different as analyses are performed in different manners. For T2D and Stroke, the modelled operations explain a modest 5 % and 8% of variance in quality of life despite taking several evidence-based variables of operations into consideration. For Hip OA, operations explain 15% of variance in health state. We conclude that the influence of operations on outcomes is modest and/or only partly captured by the proposed models, despite the inclusion of evidence in the specification of the disease specific models. By contrast, the modelled operations' ability to explain service satisfaction is much higher with a range of 30-42%.

Table 7-2 also demonstrates that in the proposed disease specific models, demand characteristics are significantly associated with the outcomes, particularly so for stroke where the initial health state after stroke largely determines service outcomes. For the T2D networks we conclude that behaviour is significantly associated with outcomes (see [15–17] for related research), even though the present model explains a modest 4-5% of the variation in outcomes by variation in co-creating behaviour.

Often, poorer health results in intensified health service provisioning. Hence, outcomes may in turn determine service provisioning, implying that the causality of the relationship between these two model entities is bidirectional. The importance of taking this bi-directionality into account follows from the analysis in Chapters 4-6 which reject the hypothesis that more service provisioning is associated with better outcomes. Previous evidence for instance in diabetes care supports these findings [18]. Likewise, we find that costs-outcomes relationships are not consistent. In the T2D application, we find that higher costs are linked to a lower quality of life. A possible explanation is again that poor health leads to more service provisioning and hence to higher costs. This reasoning doesn't hold true for stroke and hip OA networks (where higher costs may come in the form of investing in emergency responsiveness, early diagnosis, or stroke care unit capacity). Further refinement (e.g. through segmentation) of the modelling of health state and the progression of health state in relation to service operations is likely to be needed to advance understanding on the relationship between patients characteristics, intensity of service provisioning, costs, and outcomes.

Table 7-2 Relationships between demand, behaviour, operations and outcomes

	EQ-5D			**Satisfaction with services**		
	T2D	Stroke	Hip OA	T2D	Stroke	Hip OA
Demand						
Age	-			+		
Gender	+		-			
Education						
Health states	+	+	+		+	+
Behaviour						
Alcohol consumption	+					
Smoking						
Physical activity	+					
Operations						
N. of follow up visits	-					
Comprehensiveness				+		
Rehabilitation provision		+				
Demand/provider rate		+	+			
Nurse based structure (Diabetes and hip OA)	+		+			
Stroke care unit (Stroke)		+				
Service use	-	-	-			
Costs	-	+	+			
Non-urgent access	-	-				
Urgent access		-				
Scheduled access	-	-	-	-		
Tangibles				+	+	+
Timeliness						
Responsiveness				+	+	+
Empathy						-
Caring				+		+
Communication						+
Explained variance (%) by:						
Demand	11-12	11	3	1	5	2
Behaviour	4-5	2	NA	0-1	0	NA
Regions	NA	1	1	NA	2	1
Operations	5	8	15	41-42	36	30
Total amount of explained Variance (%)	21-22	22	19	42-44	44	33

The effects of structure are for instance shown by our study of the roles of professionals in T2D networks. We found that regions with a larger role for nurses in diabetes care are more efficient and effective. Likewise, the geographical context and network structures and capacities influence access to services through travel distances and waiting times. Longer distance and waiting time are negatively associated with health outcomes in the three disease networks investigated.

Health service quality dimensions determine satisfaction with services [19, 20]. Among the evidence based dimensions found in previous research, our research confirms that tangibles, responsiveness, and communication are significantly and positively associated with satisfaction with services. Non-significant relationships, and in particular the significant negative relationship between empathy and service satisfaction, raise questions about the generalizability of service quality measurement instruments across diseases and regions (cultures). Moreover, the negative correlation between empathy and satisfaction invites further research.

In summary, and with reference to Table 7-2 we recommend the following evidence based practices for health service provider networks per disease:

a) Type 2 Diabetes
   - Provide Type 2 Diabetes services with short waiting times as is associated with better health outcomes
   - Use a collaborative GP/nurse resource model, with a larger role for nurses as is associated with better health outcomes
   - Provide such services, comprehensively, and in a responsive and caring manner using appropriate tangibles (up-to-data equipment) as is associated with increased service satisfaction.

b) Stroke
   - Provide fast emergency response as is associated with better health outcomes
   - Admit all patients to a dedicated stroke care unit as is associated with better health outcomes
   - Provide subsequent rehabilitation services as is associated with better health outcomes
   - Provide appropriate tangibles and responsive services to increase satisfaction.

c) Hip OA
   - Provide services with short waiting time from decision to surgery as is associated with better health state
   - Provide appropriate communication by service providers to service users as is positively associated with improved service user ability to perform the activities of daily living.
   - Provide such services in a responsive way, with caring professionals and tangibles of services as are positively associated with service satisfaction,

7

Theoretical and Methodological Considerations

Theoretical reflection

Most operational modelling studies are case specific, do not build on previous studies, and are not repeated nor extended in follow-up studies. This leads to specific models with little progress towards “generalizable insights or general theory” [7]. Using a number of applications that rely on a generic framework this research made it feasible to generate a general framework for modelling and analysis of regional provider networks.

The framework and models in this research can be positioned at the third level of Fletcher & Worthington's spectrum of genericity of models [21]. In this level a generic framework is developed that is health care industry-specific and can be used for multiple providers and diseases. Our framework provides templates for translation of the generic health operational model to disease models and instantiation of the disease models to various health operations settings. To our best knowledge, despite calls for a systematic generalizable framework [7] there is no such framework available for different diseases and various health service provider networks. The framework presented in this thesis facilitates applications in different settings and therefore facilitates generalizable insights. Moreover, the FP7 project Managed Outcomes has shown that the methods of specification and instantiation can be applied by researchers and practitioners not stemming from an operations management background.

The modelling framework has acted as a basis for modelling operations of networks and the analysis method has identified relationships between operations and outcomes and among other model entities as intended. The method of analysis works in both directions from differences in outcomes to differences in operations, and from differences in operations to differences in outcomes to enhance completeness of the analysis. As the explained variance in quality of life ranges from 19-22% (according to Table 7-2) and the explained variance in satisfaction with services ranges from 33% to 44%, where 30% to 36% is attributed to operations, our empirical evidence supports the validity of the models. At the same time, the empirical findings indicate that the models and analysis leave room for further evidence regarding the relationships between operations and outcomes.

Limitations of the study design

The research design which has been adopted in this research is prone to several limitations. In this research, relationships between operations and outcomes for demand segments or provider networks are studied using a small size observational study or multiple case study, which limits the external validity and strength of the evidence provided. Given that provider networks rather than patients form our primary unit of analysis, recruiting a large population (of networks) - as beneficial to the quality of the evidence- is however practically infeasible.

The cross sectional approach limits the attribution of effects of differences in services on differences in outcomes, thus also weakening the internal validity [22]. The contribution of this research is therefore to be seen as a step in the process of advancing the evidence base for health service operations in networks, through the proposed generic framework and subsequently derives models, as advocated by Berwick [23]. The resulting models capture the characteristics of processes and outcomes as called for by the Medical Research Council [10]. They do facilitate accumulation of results from earlier studies, and thereby further advancement of internally and externally valid relationships between health service operations and outcomes.

In real life, many contextual factors which have been disregarded in this thesis may play a role. One might think of political and economic contextual factors [13]. Incorporating these factors into the model may enlarge the explained variation and impact the attribution of effects to differences in health services[24]. We note however, that context is unlikely to be completely included in the models as proposed in this thesis and analysis framework.

Recommendation for research

As an important and growing fraction of the present burden of disease stems from age and life style related chronic conditions, the emphasis of health services operations research should turn to long term care network settings [25], as opposed to sub optimization of departmental or organisational settings [6]. Explicit inclusion of outcomes next to efficiency and costs is subsequently required for this research to contribute to understanding and effectiveness of the networks.

Improvement of the generic framework is certainly possible. The framework can be applied to other chronic diseases and other settings to improve the applicability and validity. It may also consider multi-morbid conditions since 36% of all patients suffer from a combination of diseases [24]. Alternatively, future research may consider extending the demarcation of studies to embrace the service journey from the onset of disease to death, and, for instance, preventive and primordial services in stroke patients [26].

To strengthen the quality of the generated evidence, we advocate further research to add instances to the type 2 Diabetes study, the Stroke study and the Hip OA study. More generally, we encourage future researchers to include larger numbers of networks when using observational designs [27]. In addition, we advocate experimental designs and intervention studies with the aim to generate higher level evidences. Particularly at the service user level it is feasible to randomize patients in a multiple case study setting and deliver stronger evidence [28].

The nature of the relationship between health operations, (intermediate) clinical outcomes, and quality of life is worthy of further exploration. In this research we investigated the relationships between operations and health state and quality of life. We suggest future research to study relationships between operations and intermediate outcomes as well as relationships between intermediate outcomes and quality of life, using designs which can address bi-directionality of these relationships.

Based on our findings, we believe that combining theories and models from service operations management and health services research has produced novel and insightful results. Certainly, this bridge between the two scientific disciplines can be strengthened and broadened further, and we expect that it will generate scientific understanding that can contribute to the improvement of health services for urgent and highly prevalent diseases and hence to the health and service satisfaction of populations.

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Summary

Summary

The purpose of this thesis was to develop a framework for modelling and evaluation of evidence-based health service operations in disease-focused provider networks. This research was developed in three phases: in the first phase, we investigated health and service operations management literature with the aim of finding generic health service operational models (Chapter 2). In the second phase, having learned from the literature review, a generic framework for modelling and evaluating health service operations was developed (Chapter 3). In the third phase, the generic framework was applied into regional provider networks of Type 2 Diabetes, Stroke, and Hip Osteoarthritis (Chapters 4-6).

In Chapter 2 of this thesis we systematically reviewed current service operations management literature and healthcare research literature in order to synthesize evidences on generic models. The Managed Outcome project motivated us to search for reusable models and frameworks that can facilitate multiple applications. A generic operational model is a representation of health service operations performed to meet patient demands. Such models are applicable to a wide range of disease networks and instances of a disease network.

The systematic review included 116 out of 4000 peer-reviewed papers published between 1990 and 2010. Synthesized evidences answered four main questions: 1) why are models used? 2) what is modeled? 3) what models are used and how are they developed? and 4) what are the achievements? Although health outcomes are expected to be the main purpose and objective of models, few studies consider health outcomes and therefore few insights are available with regard to how operations affect outcomes. Our findings also confirm the evidence of previous reviews that the reuse of existing research results in new models and solution methods is remarkably low. Moreover, studies often fail to produce “generalizable insight” for further modelling applications. Most operational models consider health service operations of/for elective and emergency conditions; whereas, operational models of/for long term care or chronic care are rarely developed. In most health operational models either organizational or departmental settings rather than provider networks are addressed.

In Chapter 3 a generic framework for modelling and evaluation of health service operations was developed. The framework encourages replications through multiple applications to diverse diseases and instances. The framework enables modelling at two main levels; the generic level and the disease-specific level. At the generic level five main entities are considered: Demand, Services, Structure, Behaviour, and Outcome. The generic entities are further broken down to capture details of health service operations, behavior, and outcomes. The framework also provides a bi-directional analysis strategy to capture relationships between differences in outcomes and differences in operations. This chapter also illustrates a case study in which the framework was applied to describe and analyze the provider network of type 2 diabetes care in Rotterdam, The Netherlands. The analytical strategy uses regression models to explore how differences in outcomes can be

described by differences in operations and then how differences in operations lead to differences in outcomes.

In Chapter 4 we applied the generic framework for modelling and evaluating provider networks of type 2 diabetes in primary care. This is the first case study among three studies to investigate the application of the generic framework to diverse diseases and instances. We used a diabetes-specific model, derived from the generic framework, to analyze relationships between service operations and outcomes. This model describes the demand for health services, the health service network and the outcomes obtained. In the next step six case studies in six European countries are described using the diabetes model. Subsequently, relationships between differences in outcomes and differences in operations were investigated mainly using regression models.

In the analyses of outcomes we focused on three measures: Glycated haemoglobin level (HbA1c); health related quality of life, and satisfaction with services. Having controlled for differences in demand characteristics in the six different European regions, regression models explain 28% of the variance in EQ-5D health related quality of life; almost half of the explained variance is related to demography and behavior. The regression modeled explained 46% of variance in satisfaction with services,to a large extent through service operations. Confirming previous evidence, our study found a positive correlation between the involvement of nurses in type 2 diabetes care and quality of life. The analysis identifies several operational characteristics of regions which obtain better outcomes, both in terms of percentage of patients with a controlled HbA1c level, and in terms of quality of life at lower health service use and lower costs. The operational models, which capture service operations at the network level rather than at the patient level, explain as much of the variance in quality of life by service operations as by (demographic) demand factors. Given the contributions of operations to explain health outcomes and particularly service satisfaction the diabetes model provides a sound basis to advance evidence-based analysis and understanding type 2 diabetes provider networks.

Chapter 5 presents the second study, in which the framework is applied to to secondary care networks, more specifically to stroke service provider networks. As a first step, we developed a stroke-specific model from the generic model. It describes demand, services, structure, behavior, and outcomes. Subsequently, this model is used to describe secondary care networks for stroke care in six European countries. Finally, based on the bi-directional analytical strategy, the operations-outcomes relationships analyzed using hierarchical and logistic regression models.

Applying the analysis strategy to the patient level and to the network level resulted in neutral or positive relationships between operations and outcomes. Emergency and diagnosis services in either level of analysis positively affect health outcomes. However, the relationships regarding the structure in which acute treatment is provided and outcomes appeart to be ambiguous. A logistic regression at patient level revealed no relationship between direct admission to stroke care unit and health state, whereas the analysis at network level suggests positive effects on health state. Like in type 2 diabetes case, service operations explained more than a half of the variance in satisfaction with services; The service operations explain,however, only a limited part of the variance in health state. Our models and findings advance evidence on the relationship between outcomes and operations in stroke service provider networks. Still, the evidence falls short of explaining the majority of variance in health outcomes of stroke provider networks.

Chapter 6 presents the third application study of the generic framework for modelling and evaluating health service operations. In this study the generic model provided a basis to develop a hip osteoarthritis model. Using this disease model we described six case instances of hip osteoarthritis in six regional provider networks in the European countries.

Analyses were performed at both patient level and network level using the bi-directional analysis strategy. Using a set of regression models, EQ-5D health related quality of life, pain, impaired usual activity, and service satisfaction were analysed. The model explained a limited part (19%) of variance in EQ-5D of which 16% was attributed to operations, mostly via the ServQual dimensions. Waiting time showed a negative correlation with pain. After control for diverse demand characteristics between regions, demographic characteristics had the largest contributions to explain pain and impairments. Unlike the diabetes and stroke models, the hip osteoarthritis model explained only 33% of differences in satisfaction with services of which 30% of the explained variance is attributed to operational differences. Given the limited amount of explained variance of health states, we consider the model to provide an initial basis to relate differences in health outcomes to differences in health service operations.

In Chapter 7 discussion and conclusions were presented. The first paramount conclusion is that few health operational models consider health outcomes, chronic diseases and multi-morbid conditions, and provider networks. As a result, little evidence exists on operations-outcomes relationships especially for age and life style related chronic conditions.

The contribution of our research is an evidence base on health service operations by systematic modelling and subsequent empirical analyses using a generic framework. Our empirical analyses show directions of effects from differences in outcomes to differences in operations, and from differences in operations to differences in outcomes; thus enhancing completeness of the analysis. Our empirical results support the validity of the models. The analyses of operations-outcomes relationships using the bi-directional analysis strategy support that relationships between operations and outcomes are not unidirectional given the fact that provider networks are created by various entities between which various types of relationships exist. Such relationships between networks' entities are difficult to capture using unidirectional analysis approaches.

The generic framework and further disease models have yet much room for advancement. In particular, the framework is applied through multiple cross-sectional studies that weakens the attribution of effects in any directions thus weakening the internal validity. Furthermore, our empirical analyses suffer from disregarding contextual factors such as economic and political factors. However, taking a broader perspective and incorporating the contextual factors into the model may enlarge the explained variation and impact the attribution of effects to differences in health services. Let it be noted however, that taking all relevant contextual variables into consideration appears impossible.

Future research certainly can improve the generic framework as well as empirical analyses. The framework can be applied to study other chronic diseases, other settings, multi-morbidity, or more embracing the patient journey from even preclinical stage of diseases to death. Based on our findings, we believe that combining theories and models from service operations management and health services research has produced novel and insightful results. Certainly, this bridge between the two scientific disciplines can be strengthened and broadened further, and we expect that it will generate scientific understanding that can contribute to the improvement of health services for urgent and highly prevalent diseases and hence to the health and service satisfaction of populations.

Samenvatting

Samenvatting

Dit proefschrift richt zich op het ontwikkelen van een raamwerk voor modellering en evaluatie van evidence-based health service operations in ziekte specifieke netwerken van zorgaanbieders. Het onderzoek kende drie fasen: in de eerste fase is de literatuur op het gebied van health service operations management bestudeerd om generieke health service operations modellen te vinden (Hoofdstuk 2). In de tweede fase is op basis van het literatuuronderzoek het generieke niveau raamwerk voor modellering en evaluatie van health services operations ontwikkeld (Hoofdstuk 3). In de derde fase is het generieke niveau raamwerk toegepast op regionale netwerken van zorginstellingen voor Diabetes type 2, CVA en Heup Osteoartritis (Hoofdstuk 4-6).

In hoofdstuk 2 van dit proefschrift hebben we de huidige literatuur op het gebied van service operations management en health services research onderzocht op evidentie van generieke modellen. Het Managed Outcomes project motiveerde ons om te zoeken naar hergebruik van modellen en raamwerken die verschillende toepassingen mogelijk maken. Een generiek operationeel model is een representatie van health service operations als antwoord op zorgvragen van patiënten. Dergelijke modellen zijn toepasbaar voor een brede range van specifieke zorgnetwerken en realisaties van een specifiek zorgnetwerk.

Het systematic review omvatte 116 van 4000 peer-reviewed artikelen gepubliceerd tussen 1990 en 2010. De evidentie richtte zich op beantwoorden van vier hoofdvragen: 1) waarom worden modellen gebruikt? 2) wat wordt gemodelleerd? 3) welke modellen worden gebruikt en hoe zijn ze ontwikkeld? en 4) welke prestatie hebben ze gerealiseerd? Alhoewel verondersteld wordt dat betere zorguitkomsten het belangrijkste doel zijn van modellen, zijn er slechts weinig studies die zorguitkomsten bestuderen en is er daarom weinig inzicht beschikbaar op welke wijze operations uitkomsten beïnvloeden. Onze bevindingen bevestigen ook de evidentie van voorafgaand onderzoek dat opvallen weinig gebruik wordt gemaakt van resultaten van eerder onderzoek bij het ontwikkelen van nieuwe modellen en oplossingen. De onderzoeken produceren nauwelijks “generaliseerbaar inzicht” voor toepassing in vervolgstudies. De meeste operationele modellen richten zich op health service operations voor planbare en spoed zorg, terwijl operationele modellen voor langdurende zorg of chronische zorg weinig worden ontwikkeld. De meeste operationele modellen hebben betrekking op organisaties of afdelingen en niet zozeer op netwerken van zorgaanbieders.

In hoofdstuk 3 wordt een generiek raamwerk voor modellering en evaluatie van health service operations uitgewerkt. Het raamwerk stimuleert herhaling door meervoudige toepassing voor verschillende ziektebeelden en situaties. Het raamwerk maakt het mogelijk om op twee hoofdniveaus te modelleren: het generiek niveau en het ziekte specifieke niveau. Op het generiek niveau worden vijf hoofdentiteiten onderscheiden: Zorgvraag, Services, Structuur, Gedrag en Uitkomsten. De generieke entiteiten zijn verder uitgesplitst om details van health service operations, gedrag en uitkomsten te kunnen beschrijven. Het raamwerk biedt ook een twee-richtingen analyse strategie voor de relaties tussen verschillen in uitkomsten en verschillen in operations. Dit hoofdstuk illustreert ook een casestudy waarin het raamwerk is toegepast voor het beschrijven en analyseren van netwerken van zorgaanbieders voor diabetes type 2 in Rotterdam. De analyse strategie maakt gebruik van regressie modellen om te verkennen hoe verschillen in uitkomsten kunnen worden beschreven door verschillen in operations en vervolgens hoe verschillen in operations leiden tot verschillen in uitkomsten.

In hoofdstuk 4 pasten wij het generieke raamwerk voor modellering en evaluatie van netwerken van zorgaanbieders toe op diabetes type 2 in de eerstelijns gezondheidszorg. Dit vormt de eerste casestudy van drie studies om de toepasbaarheid te onderzoeken van het generieke raamwerk voor verschillende ziektebeelden en situaties. We gebruikten een diabetes-specifiek model, afgeleid van het generieke raamwerk om de relaties tussen service operations en uitkomsten te analyseren. Dit model beschrijft de zorgvraag voor health services, het netwerk van zorgaanbieders en de verkregen uitkomsten. In de volgende stap worden zes casestudies in zes Europese landen beschreven met behulp van het diabetes model. Vervolgens werden de relaties tussen verschillen in uitkomsten en verschillen in operations onderzocht met gebruikmaking van voornamelijk regressie modellen.

In de analyse van uitkomsten richten we ons op drie maatstaven: het geglyceerd hemoglobine niveau (HbA1c), de zorg gerelateerde kwaliteit van leven en de tevredenheid over de services. Gecorrigeerd voor verschillen in zorgvraag vanwege de verscheidenheid van zes verschillende Europese regio's, verklaarden de regressie modellen 28% van de variantie in de EQ-5D zorg gerelateerde kwaliteit van leven, waarvan bijna de helft gerelateerd aan demografie en gedrag. Het was mogelijk om in totaal 46% van de variantie in tevredenheid met services te verklaren met een regressie model maar dit kon in grote mate aan service operations toegewezen worden. In overeenstemming met eerder onderzoek toont deze studie positieve correlaties aan tussen een grotere rol voor verpleegkundigen in diabetes type 2 zorg en kwaliteit van leven. De analyse identificeert verschillende operationele karakteristieken van regio's met betere uitkomsten, zowel in termen van het percentage patiënten met een gereguleerd HbA1c niveau als in termen van kwaliteit van leven, bij minder gebruik van health services en lagere kosten. De operationele modellen, die betrekking hebben op service operations op het netwerk niveau in plaats van op het individuele patiënt niveau, verklaren evenveel variantie in kwaliteit van leven door service operations als door (demografische) zorgvraag factoren. Gegeven de bijdragen van operations aan het verklaren van gezondheidsuitkomsten en in het bijzonder tevredenheid over services verschaft het diabetes model een stevige basis voor evidence-based analyse en begrip van diabetes type 2 netwerken van zorgaanbieders.

Hoofdstuk 5 presenteert de tweede studie met toepassing van het generieke raamwerk in tweedelijns zorgnetwerken. In dit hoofdstuk wordt het generieke raamwerk toegepast voor bestudering van netwerken van zorgaanbieders voor CVA service operations. In de eerste stap is op basis van het generieke raamwerk een specifiek model ontwikkeld voor CVA. Het beschrijft de zorgvraag, de services, de structuur, het gedrag en de uitkomsten. Vervolgens wordt het model gebruikt om tweedelijns netwerken voor CVA zorg te beschrijven in zes Europese landen. Tenslotte worden op basis van de twee-richtingen analyse strategie de relaties tussen operations en uitkomsten geanalyseerd, gebruik makend van hiërarchische en logistische regressie modellen.

Toepassing van de analyse strategie op patiënt niveau en netwerk niveau resulteerde in neutrale of positieve relaties tussen operations en uitkomsten. De analyse voor spoed en diagnostische services resulteerde op beide analyse niveaus in positieve effecten voor gezondheidsuitkomsten. De analyse van de structuur van leveren van spoedzorg leidde tot tegenstrijdige effecten. Een logistische regressie op patiënt niveau gaf geen zicht op een relatie tussen directe opname op een stroke care unit en gezondheidstoestand, terwijl de analyse op netwerk niveau positieve effecten suggereert voor de gezondheidstoestand. Net zoals in de diabetes case verklaren de service operations meer dan de helft van de variantie in tevredenheid met services; daarentegen kan maar een beperkt deel van de variantie in gezondheidstoestand worden verklaard door service operations. Onze modellen en bevindingen dragen bij aan evidentie aangaande de relatie tussen uitkomsten en operations in stroke service netwerken van zorgaanbieders. Desondanks is er sprake van onvoldoende evidentie om de meeste variantie in gezondheidsuitkomsten van CVA netwerken te verklaren.

Hoofdstuk 6 presenteert de derde toepassing van het generieke raamwerk voor modellering en evaluatie van health service operations. In deze studie is uit het generieke model een specifiek model voor heup osteoartritis afgeleid. Met behulp van dit ziekte-specifieke model hebben we zes voorbeelden van heup osteoartritis in zes regionale netwerken in de betrokken Europese landen beschreven.

Er zijn analyses verricht op zowel patiënt niveau als netwerk niveau, gebruik makend van de twee-richtingen analyse strategie. Met behulp van regressie modellen zijn de EQ-5D gezondheid gerelateerde kwaliteit van leven, pijn, beperkingen in dagelijkse activiteiten en service tevredenheid geanalyseerd. Het model verklaart een beperkt deel (19%) van de variantie in EQ-5D waarvan 16% toegerekend kan worden aan operations, meestal via de ServQual dimensies. Wachttijd laat een negatieve correlatie zien met pijn maar niet voor dagelijkse activiteiten. Na correctie voor verschillen in zorgvraag karakteristieken tussen regio's dragen demografische kenmerken het meeste bij aan het verklaren van pijn en beperkingen in dagelijkse activiteiten. In tegenstelling tot de diabetes en CVA modellen verklaart het heup osteoartritis model 33% van de verschillen in tevredenheid met services, waarvan 30% van de verklaarde variantie toegewezen kan worden aan operationele verschillen. Gegeven de beperkte hoeveelheid verklaarde variantie van in het bijzonder de gezondheidstoestand kan worden gesteld dat het model een initiële basis biedt om verschillen in gezondheidsuitkomsten te relateren aan verschillen in health service operations.

In hoofdstuk 7 worden de discussie en conclusies gepresenteerd. De eerste opvallende conclusie is dat weinig operationele modellen in de zorg zich richten op gezondheidsuitkomsten, chronische ziekten, multi-morbiditeit en netwerken van zorgaanbieders. Dit heeft weinig evidentie opgeleverd over de relatie tussen operations en uitkomsten, in het bijzonder voor leeftijd en leefstijl gerelateerde gezondheidsproblemen.

De bijdrage van ons onderzoek is een evidentie basis voor health service operations door systematische modellering en vervolgens empirische analyses gebruikmakend van een generiek raamwerk. Onze empirische analyses laten de richting van effecten zien van verschillen in uitkomsten naar verschillen in operations, en van verschillen in operations naar verschillen in uitkomsten; ze onderstrepen het streven naar compleetheid van analyses. Onze empirische resultaten onderbouwen de validiteit van de modellen. De analyses van de operations-uitkomsten relaties met gebruik van de twee-richtingen analyse strategie ondersteunen het gegeven dat relaties tussen operations en uitkomsten niet in één richting werken, gegeven het feit dat netwerken van zorgaanbieders opgebouwd zijn uit verschillende entiteiten waartussen verschillende type relaties bestaan. Voor analyse van dergelijke relaties tussen de entiteiten van netwerken is een eenrichting analyse benadering ontoereikend.

Het generieke raamwerk en de ziekte specifieke modellen laten nog veel ruimte voor verbetering. Het raamwerk is toegepast in meervoudige cross-sectional studies die de toerekening van effecten in een bepaalde richting verzwakken en daardoor ook afbreuk doen aan de interne validiteit. Bovendien hebben onze empirische analyses beperkt oog voor contextuele factoren zoals economische en politieke factoren, die buiten onze invloed lagen zoals veelal het geval is in onderzoek. Daar staat tegenover dat als we een breder perspectief hadden gehanteerd en de contextuele factoren in het model hadden kunnen opnemen, de verklaarde variantie groter was geweest en de effecten beter toewijsbaar waren geweest naar verschillen in health services. Het mag echter duidelijk zijn dat het haast onmogelijk is om alle relevante contextuele variabelen mee te nemen.

Verder onderzoek kan zeker bijdragen aan verbetering van het generieke raamwerk evenals aan de empirische analyses. Het raamwerk kan toegepast worden voor bestudering van andere chronische ziekten, andere situaties, multi-morbiditeit, of uitbreiding van het patiënttraject van preklinische fasen van ziekte tot aan het overlijden. Op basis van onze bevindingen zijn we ervan overtuigd dat het combineren van theorieën en modellen van service operations management en health services research heeft geleid tot nieuwe en inzicht gevende resultaten. Zeker, deze brug tussen de twee wetenschappelijke disciplines kan verder versterkt en verbreed worden. We verwachten dat dit leidt tot wetenschappelijke inzichten die kunnen bijdragen aan verbetering van zorg voor urgente en veelvoorkomende ziekten en derhalve aan de gezondheid en tevredenheid van mensen.

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Mahdi Mahdavi

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Rotterdam

Curriculum Vitae

PhD Portfolio

Name: Mahdi Mahdavi

Department/institute: Department of Health Services Management and Organization, Institute of Health Policy and Management

Study period: 2009-2014

Promotors: Professor Jan Vissers & Professor Joris van de Klundert

Publications

Mahdavi, M., Malmstrom, T., van de Klundert, J., Elkhuizen, S., Vissers, J., (2013), "Generic operational models in health service operations management: a systematic review." Socio-Economic Planning Sciences, Volume 47, Issue 4, Pages 271–280.

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Conference presentations

1st National Conference on Health Insurance and Economics, Modares University, Tehran, Iran, 2009 (Best paper Award).

37th annual meeting of the EURO working group on Operations Research Applied to Health Services (ORAHS), Cardiff 2011.

23rd Annual POMS Conference, Chicago, IL, U.S.A. 2012.

4th Service Operations Management Forum Workshop, Florence, Italy, 2012.

39th annual meeting of the EURO working group on Operations Research Applied to Health Services (ORAHS), Istanbul 2013.

Short courses and workshops

Operations research applied to health services, Utrecht University, Utrecht, The Netherlands, 2010.

Academic writing in English, iBMG, Erasmus University Rotterdam, Rotterdam, The Netherlands, 2011.

Service Operations Management, 4th EurOMA Summer School, Budapest, Hungary, 2012.

Service design, 4th EurOMA Summer School, Budapest, Hungary, 2012.

Multi-Channel and E-Services, 4th EurOMA Summer School, Budapest, Hungary, 2012.

Public Services, Global Services, 4th EurOMA Summer School, Budapest, Hungary, 2012.

Service Supply Chains, 4th EurOMA Summer School, Budapest, Hungary, 2012.

Service Management: Operations, Strategy, and Information Technology, Erasmus University Rotterdam, Rotterdam, The Netherlands, 2012.

Health services process modelling and simulation, Erasmus University Rotterdam, Rotterdam, The Netherlands, 2012.

Evidence-based health service management, Expertise Centre Healthcare Logistics, iBMG, Erasmus University Rotterdam, Rotterdam, The Netherlands, 2012.

Project management and networking, PhD career day, Erasmus University Rotterdam, Rotterdam, The Netherlands, 2012

Futures Workshop, Managed Outcome Project, Rotterdam, The Netherlands, 2012.

Modelling stochastic healthcare processes, 39th annual meeting of the EURO working group on Operations Research Applied to Health Services (ORAHS), Istanbul 2013.

About the author

Mahdi Mahdavi was born in Hamedan, Iran in 1980. He obtained his bachelor degree in Public Health in 2004 at Hamedan University of Medical Sciences (UMSHA). He then shifted his graduate education to health services management and sat for a national university entrance exam for the master degree in Health Services Management. He ranked top 3rd student in this exam. He graduated in MSc. of Health Services Management from Tehran University of Medical Sciences in 2007 with an outstanding mark for his thesis (19.95 out of 20). From 2007 until December 2009 he has worked as researcher and consultant for the development of health services management in UMSHA. In 2008 he ranked top 1st student in the national university entrance exam for PhD in Health Policy for which he received comprehensive scholarship to pursue a PhD study abroad.

In December 2009 he joined the Institute of Health Policy and Management of Erasmus University Rotterdam as a scientific researcher. He was contracted to contribute to the Managed Outcomes project in The Netherlands. Managed Outcomes was a 3-year project financed by the European Framework Programme FP-7 for health, performed in 2010-2012 by a consortium of universities. The Managed Outcomes project has proven to be a personally stimulating undertaking and has provided him with opportunities and skills to research healthcare operations management in primary and secondary care settings in six European countries. Operating within such a large multinational and multidisciplinary project involving researchers from academia and the private sector was challenging and stressful at some times but rewarding in the end.

He enjoys being part of the health services management scientific community as a fast-developing sector of health services research. He is planning to continue his career as researcher and consultant in health service operations management of provider networks. He is interested in modelling chronic disease service operations, evaluation of disease management programs, and developing good practice healthcare models at regional level.