Towards a Systems Model of Healthcare

A prototype decision support simulation
using model based systems engineering
and thematic analysis

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Neil Michael McEvoy P.Eng. CHE

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Acknowledgements

It is humbling to realize how little we can do without the help and support that surrounds us every day, from people we know and from those we don't. Three people in particular have provided immeasurable support in the journey on which this dissertation has taken me.

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To each I extend my heartfelt thanks.

Abstract

THIS DISSERTATION DESCRIBES the development and assessment of a new model for the analysis and design of healthcare systems. Motivated by a need to better address the challenges still facing the provision of adequate healthcare services, it offers a model that can explain how healthcare functions as a whole system, and supports predicting the outcomes of policy interventions.

DETERMINING WHAT MODEL would satisfy the requirements of such a system is decomposed as (i) a design question asking *how to construct the model*,(ii) a theoretic question asking *how healthcare functions as a system*, and (iii) an evaluative question asking *how well the implemented model answers the first two.*

SUPPORT IN THE LITERATURE is found in (i) existing models, in both healthcare and broader areas of economics; (ii) model theory providing clarity on representation of explanation and prediction; (iii) systems science providing constructs, a taxonomy and a dedicated language with which to describe healthcare systemically; (iv) a broad corpus of publications in the healthcare literature providing a data set of qualitative and theoretical observations for content analysis.

THE METHODOLOGY applies Model Based Systems Engineering to the construction of a model, using a template adapted from model theory. Three versions of the model are developed to satisfy theoretic, systemic and epistemic requirements respectively. The results are reported as three related versions of a core representation of healthcare as a system; as a system composed of three familiar global systems: (i) the LifeCourse system captures how people live lives in which their health status is occasionally impaired by illness for which they may receive treatment to offset that impairment; (ii) the Provision Network, in which individuals and organizations with clinical skills and resources collectively and separately provide treatments needed in the population; (iii) in the Payment Exchange, where funds are exchanged to compensate those providers for the services they provide.

ASSESSED AGAINST THE ORIGINAL CRITERIA, that the model represent healthcare as a dynamic causal system, the systems model that emerges satisfies the requirements of a scientific model. Boundary conditions qualify the scope of each evaluation. The prototype simulation comparing the model's predicted outputs under three scenarios to historical trends of selected indicators observed in the healthcare system of the Netherlands is qualitatively comparable to the findings reported in the literature. This research extends healthcare knowledge, provides a reproducible methodology and creates an exploratory instrument to con-

duct simulated experiments in healthcare economics and health policy. Incorporation of boundary conditions points the way to future enhancements aimed at reducing those limitations and expanding the predictive capabilities of the model.

Contents

List of Figures

List of Tables

Part I: Setting the Stage

Chapter 1

Introduction: A systems model of healthcare.

This dissertation describes the development of a generalized prototype model of healthcare systems. When many countries continue to face challenges in maintaining and improving the provision of services across their populations, and long-term solutions remain elusive, this model is proposed as a practical instrument to support the planning, decision-making and implementation of healthcare reform strategies. The research premises are that such planning and implementation of healthcare reforms would be well served by a model structured as a *system*, designed with the purpose and capability to *explain* how healthcare *works as a system*, and that existing models of healthcare do not meet these combined requirements. The research develops such a systems model and assesses the limitations and the potential scope of the approach.

The dissertation offers three contributions. It extends knowledge by proposing a model that unifies healthcare as a single high level theme, deeply and broadly grounded on observations and constructs found in the literature. It applies knowledge from domains orthogonal to healthcare, such as theories and concepts of systems science, which bring rigour and precision to the patterns of healthcare as a system, while philosophical accounts of models and of explanation are adapted to designing and building a representation that is structurally and epistemologically sound and whose boundaries are well specified. The dissertations's third contribution is a reproducible methodology that enables refinement of the model's structures to avail of new data and to extend its boundaries.

This introduction places the research under the broad context of healthcare, exposing in the end some gaps in knowledge to which the research questions are directed. The chapter begins with a review of assumptions and premises about healthcare as it has evolved, and of the challenges it presents. This leads to a discussion of the roles of models in meeting the challenges, and of the adequacy of existing approaches, suggesting that, with new theory and methods, improved models of healthcare could be developed.

1.1 Assumptions and premises

Chief among the logical premises of this research is a need and an intention to improve healthcare systems, motivated by recent events and by histories of reform interventions that have often failed to realize their goals (Azzopardi-Muscat *et al.*, 2015; Burke *et al.*, 2014; Crisp, 2011; Romanow, 2002, for example). A second premise is that models are necessary in developing effective strategies for intervention and improvement. This is reasonable on the grounds that some form of conceptualization (whether conscious or not) precedes all interventions before their implementation as direct changes in the real world. Thought, discussion and planning imply forms of representation ranging from individual mental models to complex calculations and documentation. Shareable models promote collaboration and alignment. A third premise, vital to the research, is that existing models in use can be improved upon to meet the requirements of supporting effective and successful reforms of healthcare. Existing models focus deeply on particular issues, broadly on high level frameworks or passively on static descriptions, but rarely, if ever, do they combine all three dimensions.

A fourth, and crucial, premise is that despite the diversity among healthcare systems observed across different countries and jurisdictions, a core specification of healthcare can be found such that the boundary conditions address the extent to which the model circumscribes that diversity. Put simply, while countries such as Canada, the United Kingdom, the United States and Ireland have recognizably distinct healthcare systems, the assumption is that their representations draw from a common set of underlying mechanisms, while their diversity arises from the values of parameters found in those common mechanisms. Treating each national (and subnational) healthcare system as an instance of a common system is at the heart of this dissertation, and the importance of specified boundary conditions is one of its findings.

1.1.1 A need to improve healthcare

Challenges in maintaining healthcare services in many countries have grown over the past half century. Gaps persist between outcomes and intended or desired performance, with shortcomings most often observed in surveys and studies that compare countries to one another. Notably, many trace the deficiencies in healthcare performance to systemic weaknesses in implemented healthcare policy and practice.

Issues in healthcare provision

At the time of writing this dissertation, challenges confront policy makers, planners and providers in maintaining and delivering adequate healthcare services. In the United States, for example, the administration and congress have sought alternatives to the health financing regime that was introduced within the past decade (The Economist, 2017). The challenges lie in balancing a burden on public funding with an encroachment on individual choice and on provision for marginalized groups in the community. In England, the National Health Service (NHS) is under pressure (Anandaciva, 2017) to maintain levels of quality of care in the face of changing economic and political pressures. The availability of private insurance in Ireland has introduced an asymmetry in the priority of service delivery running counter to a common principle of equitable access across social and economic groups (Houses of the Oireachtas, 2017). In Canada, the single payer systems in each province attempt changes to manage expectations and budgets, routinely negotiating with the federal government on the most appropriate distribution of tax revenues (Wherry, 2017), while trying to broaden the range of services included within the publicly funded envelopes.

The challenges are not only recent. Over the past four decades, as the healthcare systems in developed countries have matured, the pressures of growing costs have added to the existing imperatives of ensuring equitable access and of improving outcomes for patients. Almost four decades ago, Wildavsky (1977) asked if "doing better" in improving healthcare was in fact leading to "feeling worse". Oliver and Mossialos (2005) more recently review the history of reform efforts in several countries as part of a parallel review in another learned journal aligning contributions both by health economists and by health policy scientists (Oliver *et al.*, 2005). Each series of articles highlights the growing economic pressures that compete with the opposing momentum to advance the technologies of the health sciences and to improve access for disadvantaged groups in societies.

The pressures have brought coalitions together. Recognizing a need to reform the healthcare system in the U.S. in the 21st century, a multidisciplinary group of researchers and practitioners collaborated in a series of workshops to develop recommendations for change. Their report (Arrow *et al.*, 2009) contains recommendations addressing financing, information, social support and taxation. Although it addresses distinct domains, the report does not reference an explicit systems model.

Individual countries have also attempted innovations and reforms over the decades. Some have succeeded, but others have fallen short of their goals.

These shortcomings are rarely reported directly, but the inadequacy of the initiatives can be inferred both in the grey literature (Anandaciva, 2017; Economist Intelligence Unit, 2016; Wherry, 2017) and in the reports of national commissions and research institutes such as Civitas (Bidgood, 2013) and The Commonwealth Fund (Mossialos *et al.*, 2016). In England, for example, Crisp (2011) recounts the urgency with which the Blair government approached reform during that administration. On a global level Britnell (2015) catalogs outstanding achievements in individual countries, obliquely pointing to the imperfections in others. Despite the breadth of the successes in his review, he acknowledges that gaps exist in every system and that no one national system can be held up as a paragon of healthcare excellence.

Commissioned reports in several jurisdictions have reviewed healthcare systems and recommended strategies to close observed gaps (Brennan, 2003; National Health and Hospitals Reform Commission, 2009, for example). In Canada the Romanow commission (Romanow, 2002) took stock of the intentions and preferences of the public at large, of their representatives and of several domain experts in determining what changes should happen in updating and refining the national healthcare system. The commission's findings led to an accord (Motiwala *et al.*, 2005) between federal and provincial governments that included new targets for the delivery of healthcare services. Many of the initiatives that have been undertaken since that time have used those targets as benchmarks against which to evaluate performance and progress. Other targets arise periodically in routine budgetary process, and in locally announced strategies.

1.1.2 Comparison in healthcare

Comparative healthcare is a field of active if not always productive inquiry. The shortcomings in healthcare systems are often evident in comparisons with one another.

WHO Report 2000

The practice of quantitative comparison has been traced (Smith and Yip, 2016) to a pivotal study conducted on behalf of the World Health Organization (WHO) (Evans *et al.*, 2001) that accompanied the seminal World Health Report (WHO, 2000). That report focuses attention on healthcare services worldwide. It compares the performance of systems in 191 countries using an efficiency frontier approach, ranking countries based on life expectancy and a uniquely developed, composite index. This study has been criticized for what were seen as methodological shortcomings (Gravelle *et al.*, 2003; Green, 2006), and it begs the question of the validity of the indicator itself. However, it successfully raises the more basic questions of efficiency in the allocation and use of resources in delivering healthcare services and has prompted other valuable contributions to the comparative evaluation of health systems internationally (Hernández de Cos and Moral-Benito, 2014; Wranik, 2012).

Commonwealth fund report: a league table

The Commonwealth Fund, a non-profit trust, has conducted surveys of healthcare repeatedly over the past decade (Davis *et al.*, 2006, 2010, 2014, 2007c; Schneider *et al.*, 2017), ranking some of the largest countries based on a few outcomes. Scores are derived from a broad set of indicators (Commonwealth Fund, 2008) covering a group of profiles and based on surveys among participating countries. Published in the grey literature, the findings have motivated closer examination of healthcare, particularly in the United States and in Canada, whose systems have consistently ranked in the last two places. However, although the "league table" approach has been successful in fostering dialogue and introspection, it does not provide quantitative comparisons and offers limited support to the discovery of innovative solutions. Oliver (2012a), for instance, asserts that comparisons based on rankings depend on the assignment of weightings that are arguably arbitrary, and seldom agreed upon. Over the years the country in the top-ranked position has changed, in part due to the expansion in the number of participating countries, but also showing improvement in performance[1] suggesting variation in performance. In summary, the information provided in the report is essentially descriptive, not analytical and neither explanatory nor predictive.

Comparison as a source of innovation strategies

Few countries attempt to reform their healthcare systems in isolation. Most investigations of prescriptive solutions are comparative in nature (Tuohy, 2012), both across large groups of countries (Davis *et al.*, 2014; Reinhardt *et al.*, 2002; Schneider *et al.*, 2017) and in smaller clusters (Häkkinen, 2005; Häkkinen and Joumard, 2007; Häkkinen and Lehto, 2005; Linna and Häkkinen, 1999; Linna *et al.*, 2006; O'Reilly *et al.*, 2012a). Almost two decades ago one author opined that "[t]he cross-national exchange of ideas and experience in healthcare reform has, in recent years, reached epidemic proportions." (Klein, 1997, p. 1267).

[1] The most recent results (Schneider *et al.*, 2017) underscore the report's merits as indicative of relative performance only; it shows a deserved ranking of England's NHS ahead of all other countries in the set, at a time when local assessments and opinion regarding the NHS point to substantial challenges still to be overcome.

Comparing countries in this way is a rich source of new ideas (Csaszar and Siggelkow, 2010; Reinhardt *et al.*, 2002). The frequency of the studies and of the strategies that have been developed as a result has increased during the decades (Cacace *et al.*, 2013; Gauld *et al.*, 2014; Marmor *et al.*, 2005, 2009; Okma and Marmor, 2013). The attraction of learning and exchanging ideas among countries is strong, as success in one jurisdiction can be used as evidence of good practice – at least in that jurisdiction's context.

Hazards of comparison

However, as alluded to by Marmor (2012), there are hazards in looking to other countries to copy strategies that have succeeded. In addressing what he terms the "unwritten rules of cross country comparison" he positions the comparative healthcare literature in the larger context of healthcare reform and improvement with two observations. In the first, he refers to *naive transplantation* where "the idea is that one searches widely for *best practices* and assumes, if found, they can be transplanted without loss from site A to site B." In this, he articulates the familiar caution that practices and strategies imported from one jurisdiction to another should be implemented only with a clear understanding of the differences in context between the two jurisdictions.

Marmor's second observation relates to *the fallacy of comparative difference* whereby "if any two sites differ from another factually, there is no respect in which they can learn from one another" (*ibid*). Underlying the logic that something can be learned through comparison is a recognition that there are similarities among healthcare systems. Where there are diversities they can be expressed and represented in a common framework. Many scholars echo this thinking, frequently concluding in their studies that comparisons among countries are best carried out using broader systems-based frameworks. Smith and Yip (2016), for example, propose that healthcare be treated as an economic system, as a premise to representing such a system as an optimization model.

As comparisons become more diverse (Burau, 2012) caution is urged in this practice of copying (Okma *et al.*, 2011; Oliver *et al.*, 2005). Beyond comparing indicators, a comprehensive analysis requires an *understanding* of the differences in institutions and institutional structures, in diversity of methods and in the evolution over time of changes in the respective healthcare systems (Marmor, 2012). Dolowitz and Marsh (2000) analyze conditions for successful transfer of policy ideas, a theme echoed by Marmor *et al.* (2009). These latter authors nonetheless note recurring gaps between performance and the promise of comparative analysis (Marmor *et al.*, 2005).

1.1.3 Observing healthcare as a system

The hazards of comparison are grounded in the larger context of healthcare's essential systemic nature. Failure to recognize influences of context can obscure differences that account for successful outcomes of a strategy in some countries yet failure of the same strategy in others.

System as a term in common usage

The term *system* is commonly applied in healthcare, at times loosely, to refer to an unspecified collective. Less frequently, but with greater intent, the term is used to convey the rich meaning of elements linked by relationships and with some purpose. Begun *et al.* (2003), for example, discuss healthcare as complex adaptive *systems*. As a contributor to the methodological debate surrounding the previously cited WHO study, Gravelle *et al.* (2003) explicitly uses the term *system* in their title. Häkkinen (2005) analyses the Finnish *system*, and Leiber *et al.* (2010) discuss the exchange of ideas between the Dutch and German health *systems*. A later chapter in this dissertation reviews studies that not only recognize the systemic nature of healthcare systems, but categorize them by type (Böhm *et al.*, 2013; Wendt *et al.*, 2009).

Avoiding unintended consequences

Improvement strategies have at times failed not because they did not realize their intended outcomes but because their efforts produced unintended consequences as well. For instance, in a study of countries that adopted diagnosis based payment to hospitals as an incentive to follow best practices, Cots *et al.* (2011) find that although the strategy appeared successful in its intended focus on practice, it also unintentionally encouraged biased selection of patients with less severe conditions. Reports of a similar study on adoption of a policy that pays providers on the basis of reported performance outcomes[2] summarizes the outcomes:

> "[t]he main finding from the case studies... is that P4P did not lead to 'breakthrough' performance improvements in any of the programmes. Most of the programmes did, however, contribute to a greater focus on health system objectives, better generation and use of information, more accountability, and in some cases a more productive dialogue between health purchasers and providers." Cashin *et al.* (2014, p. 83)

[2] *Pay for Performance*, often abbreviated to P4P, is funding based on meeting some observed quality goals.

Bishai *et al.* (2014) use a simulation model that exposes how unintended and perverse incentives can arise. Even when resources are allocated on a seemingly rational basis to support both curative services (e.g., based in hospital) and preventive services (e.g., provided by public health agencies), their model predicts counterintuitively that the curative services "crowd out" the preventive in the long run. Wolstenholme (2003) acknowledges that his motivation in assembling a catalog of archetypical modelling constructs is to expose the potential for unintended consequences in designing dynamic models of systems.

Systemic focus on performance

In general, studies that focus on particular dimensions of healthcare performance across groups of countries conclude that findings would be better assessed in a systemic model. The abstract to an article advocating an economic approach to the design of health systems begins "There has been much rhetoric in global health about the need to consider the health sector as a 'system"' (Smith and Yip, 2016). An earlier publication co-authored by Smith and Papanicolas (2013) examines healthcare performance in the context of frameworks and the indicators included within their boundaries. A recurring trope in the literature articulates in systemic terms the challenges to be met and the advances to be realized in healthcare delivery.

A common, invariant core in healthcare systems

In addition to the merits of describing healthcare as a system – because the many elements and their relationships are important to understanding – there is added value in the systems view in that it helps make sense of apparent complexity. While healthcare systems are not the same, there is an implicit and helpful assumption in comparing them. Oliver *et al.* (2005) point out that there exists a common core of invariant entities and activities across countries and that the unique features in each instance are attributable to variation in the properties of these basic and common system elements. Learning and copying across jurisdictions is possible when these elements and properties can be recognized in context. In that regard, Okma and Marmor (2013) observe that these processes are hindered by the absence of a common language and vocabulary. They recommend comparing contexts, understanding the various approaches to policy development, and treating the comparisons as opportunities for experimentation. These constructs occur in the language of systems although the cited article does not explicitly make those connections. This dissertation intentionally links the concepts.

1.1.4 Answering questions in healthcare

The challenges in healthcare provision present as deficiencies and attempts to reduce those deficiencies give rise to questions. What is happening now, and by what measure? What will happen in the future? Under what circumstances? What if some action is taken – or not? What will happen if a policy is changed? Needed remedies are to be found in answering the questions the challenges pose.

Making Sense Of Healthcare

The reason for using models is to understand the real world so that action can be taken. This is the meaning that Weick (2009) attaches to sensemaking; it is a view of the world that leads to action. As a shared view, it leads to organizational action by a group. While his discussions are often in the context of actions that have gone horribly wrong, as in the case of wild fire disasters, infectious diseases and hospitals, the general theme is that organizations must deal with the unexpected, making sense of it with what is known. This differs from the situations that confront planners and strategists, mostly in the pace of the changes they face. The scope and detail of what they face are of a similar scale, and the consequences of improper choices of no less significance. Ultimately, the value in models of healthcare systems lies both in the degree to which the representation makes sense in its own right, and in how successfully this sensemaking maps to the issues and challenges in the real world.

Challenges as questions

Comparison among healthcare systems are instructive in exposing differences in performance and in strategies. The important questions that arise relate to the potential for borrowing and adapting those strategies in new contexts; namely, what if a strategy implemented in one jurisdiction were introduced in another?

Questions in healthcare arise in several forms. Those of the first type are simply quantitative – what, how many and how much? They ask of quantities and properties themselves. They look not only at health status and access to care but also at affordability, waiting time and costs. They are the quantities measured and compared in intercountry studies.

These quantitative questions are future oriented: they ask not only of the current state of a healthcare system but what that state might evolve into with the passage of time. Epstein (2008) offers this as one of the reasons for asking "why model?" Healthcare in essence involves change, illness itself is episodic, and populations change. External circumstances create pressures and offer opportunities. Asking questions of the future calls for explanation and understanding of how the system works; interventions are put in place anticipating a positive response.

1.1.5 The questions of planning and reform

Planning and design of innovation calls for answers to *what if?* questions. In contemplating policies and strategies that might influence the outcomes of healthcare systems, the questions that planners must answer take the form

> "What could happen to *important* indicators in a *chosen* healthcare system over a *given number* of years in the future, under a *variety of circumstances*?"

The essence of designing improvement – whether it is of policies or of mousetraps – is that a future is to be caused. One of the skills is in knowing that that future will be what is intended. A second, possibly more important skill, is in predicting and avoiding an alternative future that is neither desired nor intended. History and theory provide evidence in understanding what happened previously, and assumptions may allow extending correlation as causation. However the understanding that generates new futures should allow that *what if* may not be intended or acceptable. This leads to the concept of models and artificial representations.

Many questions are contingent. They ask not only what will happen, they ask what will happen *if?* These are the questions that can or should arise in planning interventions. They are the probing questions that not only ask what is destined to happen without intervention, but explore outcomes over a range of possible scenarios, and if appropriately administered, look not only at an outcome of interest but at other outcomes that may not be of direct interest but are of importance of concern.

Finally questions are often asked in parallel. Problems do not necessarily occur one at a time, and challenges in healthcare present in many domains – (e.g., in outcomes, in access, and in patient experience and of course in expenditures.)

1.1.6 Typical questions in healthcare

There is a distinction between the questions that planners ask and the questions academic researchers ask. Planners are interested in the present and possible future states of healthcare, in such indicators as the numbers of people needing and receiving care, the costs of doing so and the sectors of society that bear those costs and benefit from their revenues. They ask questions of when?, how long? and how often? If a change is implemented in one year, for instance, when might the outcomes take effect? And when might they be observed? What if the economy contracts? What if people take better care of their own health, or new technology produces miracle cures? These are fundamental questions that must be answered in meeting the planning challenges of reforming healthcare.

They are not the questions of this research. The questions of this research concern the *means* of providing the most accurate answers to those questions. In other words, what research *tools* can be fashioned from the relevant literature.

1.1.7 Explaining healthcare with models

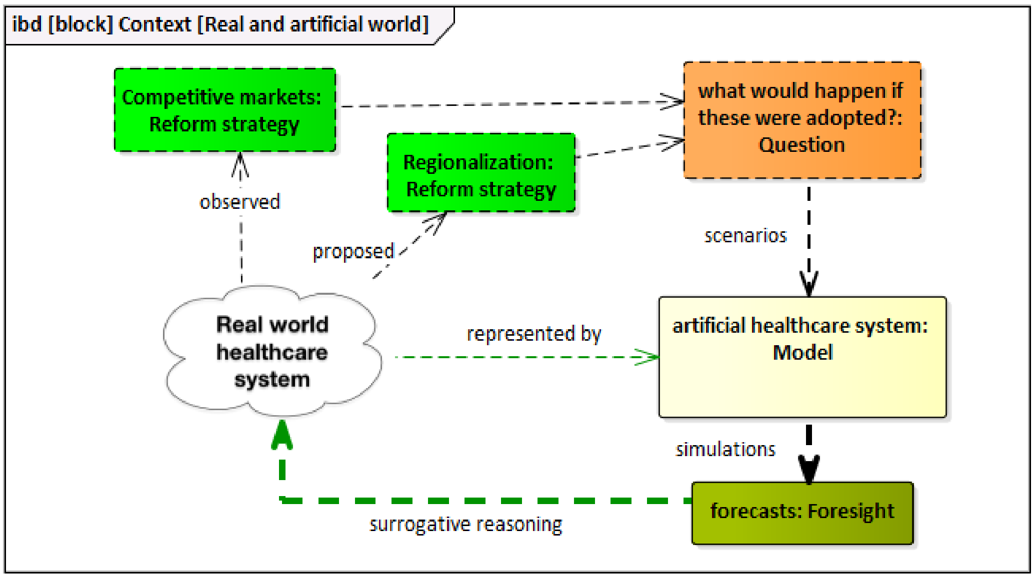


Figure 1.1: Questions may be explored safely in an artificial world, and applied in the real world if the surrogative reasoning condition is met (Author's own).

Understanding healthcare is not simple; answers to questions such as these, particularly when they are oriented to the future, can rarely by found by direct inspection and are approached instead, implicitly or explicitly, as models. Addressing the general nature of models, Frigg and Nguyen (2017a, p. 51) write "Many investigations are carried out on models rather than on reality itself, and this is done with the aim of discovering features of the things models stand for." While this is true of descriptive models, it applies with greater cogency to models built to explore and explain. Figure 1.1 illustrates a common trope in the simulation literature in which problems observed or remedies proposed are more readily framed as questions to be asked in a model's environment. This can then produce, as forecasts, a range of outcomes from which a strategy may be chosen in the real world. According to Frigg and Nguyen (2017a), scientific knowledge is acquired and organized with models, which can then be studied to discover features of the real world.

The problem solving paradigm

In the problem solving literature, one first identifies a problem around which a model is formed. An argument is made here that more complete answers (i.e., better ones) proceed as explanations from a *whole-system* view rather than from one that is *problem-centred*.

The conventional wisdom is that the first step in modelling and simulation is to identify the underlying problem, and having done so, to develop a representative model within which a solution to the problem may be produced and tested – the problem defines the context in this paradigm. Most argue for development from a problem, using domain expertise as a guide (Marshall *et al.*, 2015a; Roberts *et al.*, 2012). Checkland (2000), for example, eschews hard engineering models, preferring instead to place the problem identification and the model construction in the hands of those with a stake in the solution, although he still begins with a problem.

The prevailing wisdom approaches policy planning as problem solving where the problem at hand defines the issue/solution pairs. The advice previously mentioned urged caution in importing seemingly successful strategies from other jurisdictions without first understanding the differences in context between the donor and host systems. Identifying the borrowed solution only in the context of the immediate problem may overlook latent inconsistencies that would unexpectedly become apparent only when the borrowed solution is implemented in an environment not comprehensively and dynamically understood.

A revised paradigm for healthcare reform

In contrast to the problem-solving paradigmatic approach, this research is based on establishing a broader understanding that extends to the larger context of healthcare, in which the wider impact of problems and intended solutions can be assessed. In the language of Kuhn (2012, p.52), the paradigm changes from a purpose-built *instrument* that measures specific changes to a broadly based *test environment*, a *reference model* (Abou-Zeid, 2002) in which all relevant changes can be observed.

1.2 Building a systems model of healthcare

1.2.1 Three requirements of a systems model

Logic suggests that a *reference model of healthcare* would have particular characteristics if it is to serve as a framework within which the challenges of healthcare can be met more completely. Those requirements are that the model *represent* healthcare as a whole system within which sufficient properties and behaviours are highlighted to include the full scope and context of the system. The second requirement is that healthcare be represented as *dynamic* phenomena, capable of generating internal behaviours, and of responding to external stimuli. The third requirement flows from the second, in that planned interventions are intended to *cause* a dynamic response, making the representation clearly causal.

The first requirement recognizes that there are multiple measures by which the delivery of healthcare is assessed. In this regard, the understanding should be sufficiently *comprehensive* to include outcomes that matter to all indicating wellness and safety, equity of access and affordability of costs. It should include the range of different indicators that are valued by those with a stake in how healthcare is delivered, i.e., the people who need and benefit from it, those who provide it, and those who pay for it.

The second requirement recognizes that the context of healthcare provision is inherently *dynamic.* People age, encounter illness over time, and the resources with which care and treatment are provided are known to shift with the larger economic, technical and institutional influences of society at large. This perspective, orthogonal to the first, is also essential.

The third requirement, extending the second but unique in its own right, acknowledges that the essence of policy selection and execution is *causal.* Interventions are designed with the expressed intention of modifying or maintaining the levels of the important measures previously mentioned. In proposing and implementing such interventions (and indeed in avoiding unintended consequences of external shocks in the economy or in the population) exposing and understanding salient causal linkages is an essential aspect of a full understanding of healthcare.

1.2.2 Gaps in the literature

By this logic, there are two notable gaps in the literature. The first is in the literature of models supporting healthcare reform, the second resides in the literature of healthcare itself.

The search of the literature on healthcare system models (addressed in detail later in section 3.1) does not reveal reports of models that could serve as reference models of healthcare systems. There are many models. Some are embedded as economic analyses that either estimate the impact of selected variables, or profile the parameters of selected healthcare systems. Others explicitly simulate behaviours in organizations, of hospital departments for example, or forecast the impact of new technologies and treatment modalities on survival and recovery. To varying degrees, they describe, explain, predict and at times confirm. They may extend to include a range of relevant variables in the whole system, and they may permit interaction and experimentation. However, none is designed to include all the variables that represent the salient perspectives and characteristic dynamics of a healthcare system, and at the same time exploit the causal mechanisms that explain how the system behaves under intervention. This research explores the feasibility of combining these characteristics in a single model.

The absence of a reference model of healthcare systems exposes another gap, this time in the literature of healthcare itself. An abundance of research studies (detailed later in section 3.4) explores elements and relationships relevant to economics and policy formation in healthcare. But while some note the importance of taking a *systems view* (Hernández de Cos and Moral-Benito, 2014; Kieny *et al.*, 2017; Smith and Yip, 2016, for example), none provides a *unifying pattern* whereby the various constructs form a single, coherent system. Such a pattern, observed in the real world of healthcare, is essential in representing that real world with a model. The gap in healthcare knowledge must be narrowed if the gap in existing models is to be filled.

1.2.3 The focus of this research

The goal of this research is to propose a means of narrowing these gaps by developing a model to help answer essential planning questions more completely, thereby enhancing the efforts to improve healthcare. The model should explain how healthcare works *as a system*, including its *dynamic* and *causal* character, and should be designed to be *understood and used* by stakeholders (i.e., policy makers, practitioners, administrators) to explore and assess innovations. Of course any such explanation will be bounded by the evidence and theory on which it is based. Within the scope of this dissertation, the limited extent of the explanation is embedded in the methodology. These requirements are developed in the next chapter as a set of formal research questions to guide the construction and assessment of such a systems model of healthcare.

1.3 The design of this research

This research is designed to develop an improved model of healthcare that meets the requirements implied by gaps in the literature and by the author's experience as a participant in healthcare planning and delivery.

1.3.1 Research aim and objectives

The aim of the research is to produce a model that fills the gaps in the literature and which supports healthcare planning and delivery. The model should therefore::

The model should

- represent healthcare as a system,
- sufficiently specified to explore the consequences – intentional and otherwise – of policy interventions. These include provision of services that meet criteria of effectiveness, affordability and equity.
- built on accepted theories and constructs of healthcare and extending these constructs by exposing its systemic relationships.
- represent healthcare and its constituent elements so that planners and practitioners share concepts and plans with shared mental models and a minimum of ambiguity.

Represents healthcare as a system

The model is sufficiently specified to explore the consequences – intentional and otherwise – of policy interventions. These include provision of services that meet criteria of effectiveness, affordability and equity.

Exposes theories of healthcare

The model builds on existing theories and constructs and exposes new constructs that explain healthcare's systemic properties. Its boundaries, which determine the degree to which the model may be generalized, are established by the extent of knowledge on which it is based.

1.3.2 Research questions

The research articulates its aims and objectives in the context of three questions:

- A design question: how would a model be built to meet the requirements that have been set out?

- A theoretic question: how does healthcare work as a system?
- An evaluative question: how well does the developed model work?

1.3.3 A map of this dissertation

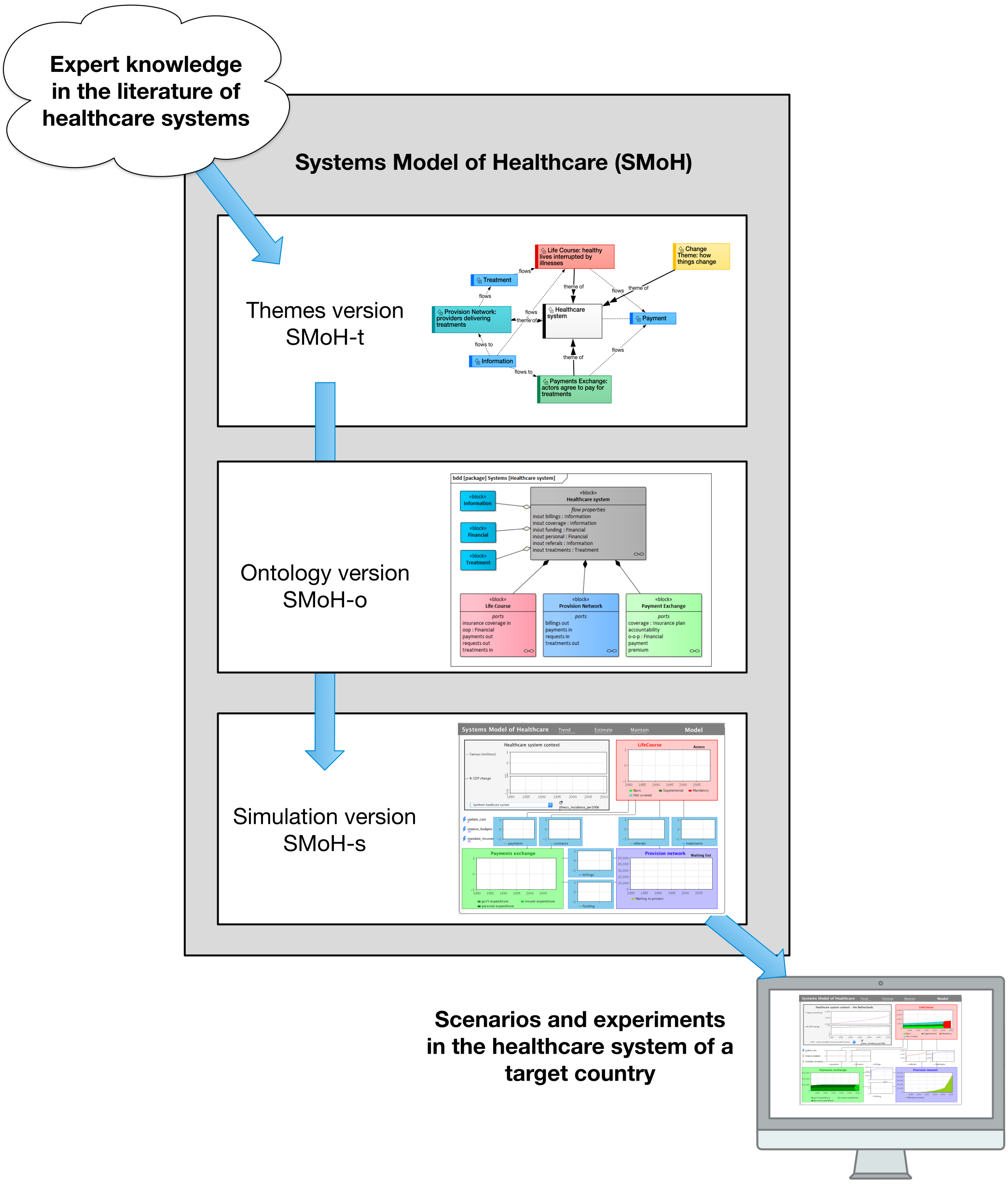


Figure 1.2: This research study develops a systems model of healthcare in three progressive versions (Author's own).

This dissertation traces the story of SMoH, a Systems Model of Healthcare designed as a prototype experimental environment in which to explore and explain how healthcare functions as a system. Figure 1.2 illustrates how the model uses expert knowledge in the healthcare literature as foundations first of an ontology and then of an interactive simulation of healthcare systems.

The next chapter unpacks the questions surrounding healthcare improvement and reform, formulating a set of research questions that guide the methodology in meeting its requirements. Figure 1.3 shows how this research study addresses these questions.

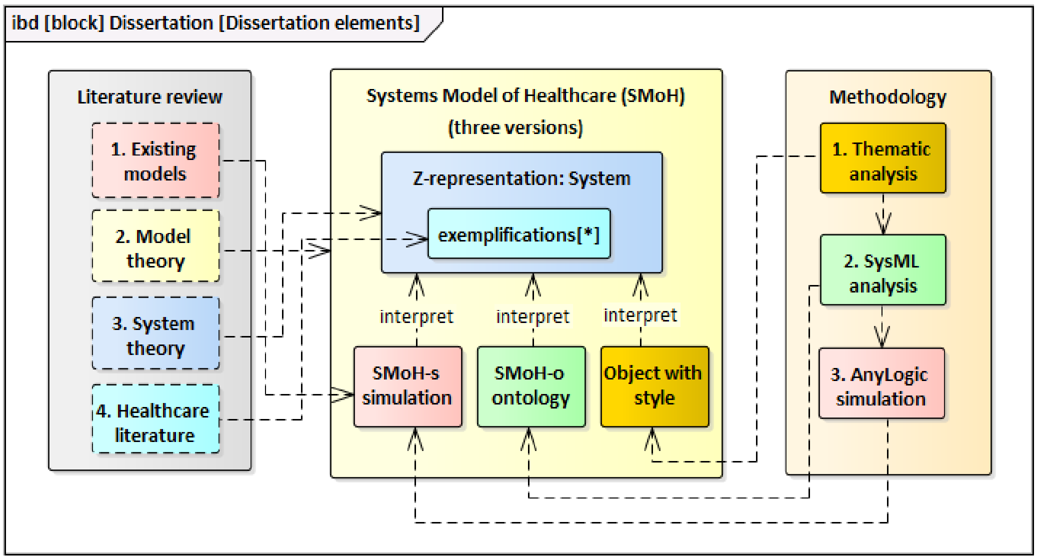


Figure 1.3: The methodology builds three versions of the systems model of healthcare by applying theory and data derived from the literature review.

The literature review in chapter 3 lays out three foundations on which to build the model. The first section reviews existing model types within healthcare domains and in the broader fields of economics, examining how their boundaries might be adapted and incorporated into a more systemic model. The literature on model theory, reviewed in the second section, describes philosophical treatments and accounts of how artificial models represent and explain targets in the real world, while theories of systems, and methods of describing them, are set out in the third section. The final section prepares an inventory of theoretical and observational studies in literature of healthcare economics and policy, with a view to establishing a knowledge base of expertise (descriptions, constructs and theory) from which essential concepts can be drawn and eventually assembled as explanatory mechanisms in the new systems model.

Building on these foundations from the literature, the methodology (chapter 4) combines three established methods to build progressively towards a sound and usable model of healthcare. The first method, thematic analysis, captures domain expertise of healthcare systems from the published literature, coalescing micro and meso patterns and constructs as a *thematic* representation of a whole healthcare system combining narrative and networks. This representation is then restated as a well-formed *systems specification* in the form of an ontology, using a formal systems language (the second method).

In the third method, a prototype software simulation is developed, based on a minimal subset of the ontology specification, and implemented in an interactive environment with which stakeholder users can explore and examine how a healthcare system works.

The emerging system model of healthcare is presented as three versions in the next three chapters: as a thematic model in a structured narrative style in chapter 5; as an ontology of structured specifications in chapter 6, and as a simulation model implemented in a software application in chapter 7. Figure 1.2 illustrates the progression from expert knowledge to scenarios and experiments. Each chapter concludes with a discussion of the boundaries of the respective versions, addressing their assumptions, and their particular merits and limitations as representations.

The discussion of the findings as a whole model (chapter 8) is framed in the context of the research questions posed in chapter 2. The assessment validates SMoH as meeting requirements of an explanatory model, reviews its limitations and expresses both dimensions as boundary conditions.

The dissertation concludes (chapter 9) with a summary of the contributions to knowledge and to practice in understanding healthcare systems. It also points to potential directions for future research.

1.3.4 Impact of this research for practitioners

The model is accessible to practitioners so that they may use it as an instrument to probe and explore healthcare strategies and policies without risk, and with mental models that can be shared. This requirement is essential if a systems model is to form the basis of discussion and debate among practitioners whose professional foundations – as policy makers, managers, providers or economists, for example – include diverse mental models.

1.4 Chapter summary

This chapter lays the foundations for the research that is described in the dissertation. The needs are traced to calls in the literature to consider healthcare from a systems perspective, and the motivation that arises from perceived shortcomings in the practice of policy and operational planning. The aim of the research is to develop a model of healthcare that meets these needs and motivations by answering three research questions.

Chapter 2

Question: How to build a model that can explain how healthcare works?

This chapter articulates the questions on which the research is founded. It begins with a core question that is motivated by the issues and challenges presented in the introduction. It then deconstructs that question as three questions to be answered within this dissertation. Each question is posed and examined in detail.

The introductory chapter placed the research in the broader context of planning and implementation of effective solutions. In this chapter, the boundaries of the research are set out as three essential questions. In later chapters, the spaces within those boundaries are filled in with reviews of the literature and with the design and application of a chosen methodology. The value of the findings is assessed, ultimately, by the degree to which they answer the questions set out here.

Building a model that can explain how healthcare works as a system is the goal of this research. The fundamental question – *what model would do that?* – leads to three primary research questions.

The first question is *one of design:* how would a model be built to serve that purpose? What components would it require, and how would it function? How would it support reasoning about healthcare systems in the real world?

This fundamental question contains, within it, a second question, which is *theoretic: how does healthcare work as a system?* What pattern explains how everything that is so widely known comes together as a single whole? Although the literature provides an abundance of theories, constructs and observations of variables, it is difficult to find in this knowledge a specified pattern of healthcare as a single system. The second research question, therefore, looks for a unifying systemic theory of healthcare.

The third question is *evaluative.* It links the first two, examining how well the model works, once it is constructed. It asks to what extent it meets its intended purpose, in terms both of its internal deductive logic and of its truth in inferring the results of that reasoning in its real world targets.

2.1 The design question: how to construct a systems model of healthcare?

The design question is formulated as follows:

> *What **model** can be constructed that represents healthcare as a system by predicting and explaining its essential behaviours?*

The question first establishes the model as its domain of interest. It provides an artificial environment of the type Simon (1996) envisages as an artificial world in which to understand and design for the real world of healthcare, which is the domain of interest in the theoretic question.

The answer to this fundamental question is embedded in the premises of the research and is articulated by the following quote:

> "Many investigations are carried out on models rather than on reality itself, and this is done with the aim of discovering features of the things models stand for. An acceptable theory of scientific representation has to account for how reasoning conducted on models can yield claims about their target systems." (Frigg and Nguyen, 2018)

It is reasonable to ask if this intended model is feasible. Healthcare appears structurally and functionally complicated, with many actors, processes, interactions and mechanisms; specifying its details can be cumbersome. The model itself could be computationally complex and representing the details could be demanding both of memory and of processing power.

On the other hand, some design techniques can tackle and implement systems that appear similarly complex and computationally challenging, by uncovering similarities and commonalities in the components, thereby taming and harnessing the diversity and complexity (Davis *et al.*, 2007a). Furthermore, although existing models may not meet all the requirements, more focused representations have been developed and have been used successfully. Combining methodologies that attend to the structure with constructs in the existing models suggests that constructing a new model of healthcare to meet the full extent of the requirements is at least feasible.

2.1.1 Parsing the design question

Parsing the design question produces three issues to be addressed in constructing the model of healthcare. *What **model** can be constructed. . . ?* asks both for a choice among types of models, and for directions on how to construct the material object as the final product of the design. The aspect of the real world to be modelled is specified in the question as *"...that represents healthcare as a system..."*. The model will realize its purpose *by predicting and explaining its essential behaviours.*

The choice of model is an essential design step. In a report on best practices in simulation, Marshall *et al.* (2015b) offers guidelines for selection among known modelling types based on features of a problem-solution pair. The choices are based on consensus among panel members. While they use the accumulated experiences of experts, the report does not indicate their theoretical foundations. Since this research takes a whole system view of healthcare rather than one focused on problem-solution pairs, it looks to more fundamental constructs and principles in model theory, reviewed later in section 3.2.

Table 2.1: Conditions of adequacy in a model-representation,

	Conditions	meaning
1	Surrogative reasoning condition	models represent their targets in a way that allows us to generate hypotheses about them
2	Possibility of misrepresentation	if the Model does not accurately represent the Target, then it is a misrepresentation but not a nonrepresentation
3	Targetless models	what are we to make of scientific representations that lack targets?
4	Requirement of directionality	models are about their targets, but targets are not about their models
5	Applicability of mathematics condition	how the mathematical apparatus used in the Model latches onto the physical world

Source: adapted from Frigg and Nguyen (2017a)

Anticipating that review, Frigg and Nguyen (2017a) suggest five conditions of adequacy as preliminary guides to the choice of model (Table 2.1). The subordinate design questions (and some available answers) are as follows:

- *What type of model?* This is a *scientific* model, in which conclusions reached in the model may be applied in the real world. It must meet the first, surrogative reasoning condition in Table 2.1. This names the model type but does not describe how it works, nor how to construct it.

- *What is the model's purpose?* The third clause in the question stipulates that the model should *predict and explain* behaviours. Addressing "How models can explain" (Bokulich, 2011) is deferred to the discussion of explanation (subsection 3.2.4) in the model theories section of chapter 3. *Purpose* in this context always implies human users who benefit from the achievement of the purpose. Since the practical intent in designing the model is to support collaboration and the formation of coalitions, the users are assumed to be of diverse backgrounds, not necessarily skilled in the disciplines of model design.

- *What does the model represent?* Once again the question provides specific guidance this time in the middle clause. It should not only *represent healthcare* but it should do so *as a system.* Condition 4 implies that the model should be parsimonious, ideally focussed on perspectives of interest, but definitely not a completely detailed replica. "The map is not the territory." (Korzybski, 2005). Furthermore, meeting condition 2 ensures that the model as constructed is sufficiently parsimonious incorporating phenomena from the real world that other phenomena are intentionally held back to validate the model. Meeting condition 5 is relevant in this research in the model specification provides for future development as a computer simulation where activities and events are implemented algorithmically.

These questions are referred forward to the literature review of model theory (section 3.2), which examines them in greater detail and provides design guidance.

2.2 The theoretic question: how does healthcare work as a system?

The theoretic question is articulated as follows:

> *Is there a **pattern** that identifies how healthcare functions as a whole system?*

Building the required representation of healthcare proposes that it reflect healthcare's systemic nature. This is a strict requirement. The ample literature on healthcare provides detailed knowledge in abundance but evidence proposing how these details align and relate as a cohesive and circumscribed whole system is notably sparse. Of course the elements and relationships can be discerned in text books and in compendia of articles, but describing a pattern that explains the collective behaviour has remained elusive.

This is a *bona fide* research (as opposed to design) question calling for theory of *what* healthcare as a system is, *how* it works and *why* (Whetten, 1989). The requirements that healthcare be represented as *explanatory* and as a *system* determine how that garnered knowledge is to be specified.

This question leads to an experimental design as the first method discussed in the research methodology (chapter 4).

2.2.1 A new theory?

In the sense that Weick (1989) equates patterns to a theory, the documented and specified model might be considered a *systems theory of healthcare*. Although a great distance from the grand deductive theories of management and of economics, it would be consistent with the assertion in Davis *et al.* (2007b) that new theory can be developed using simulation methods, given that the built model here is implemented as a software simulation.

2.3 The evaluation question: how well does the systems model work?

The third evaluative question takes the following shape:

> *What* ***boundaries*** *define and guide the use of the model as a generalized reasoning instrument?*

Evaluation is a necessary stage of a design project like this. It checks that the model meets the requirements on which its construction is based. These requirements extend along a path that originates with the user, traces the quality of the links from her interpretation of the model's data (Feinstein and Cannon, 2003), to the causal and logical structures in the representation and onwards to the model's truth, the alignment of its behaviours with corresponding known observations in its real world targets. This end-to-end evaluation construct subsumes conventional guidelines to assessing model validity (Sargent, 2005; Weinstein *et al.*, 2003). The evaluation articulates its findings as boundaries beyond which the model's patterns are not generalizable, and its reasoning may not logically or truthfully be inferred in its target.

2.3.1 Are all models wrong?

George Box is often cited for his *bon mot* that "all models are wrong but some are useful". Since this is often quoted in the context of simulation models, usually as an exculpatory apologia to get past the objections of skeptics or critics, it helps to look at the context of the citations. In Box (1976, p. 790) the quoted phrase is used as a warrant – "*since* all models are wrong" – supporting the claim that adding detail to a parsimonious model will not improve the model. Box (1979) clarifies the rationale, once again in the context of parsimony. There he asks in reference to a "cunningly chosen parsimonious model" if truth is to be interpreted as the whole truth. This begs the epistemic question: a model is wrong when the information it provides as a response to a question is demonstrably incorrect. A parsimonious model is intentionally designed *not* to answer questions of completeness. It would be more correct to assert that *all models are restricted to, and are useful for, answering questions within scope of their respective epistemic purposes.*

While the claim was undoubtedly intended to draw attention to the validity of some analytical practices – Saltelli and Funtowicz (2014) offers steps to mitigate the wrongness – it is arguably incorrect to say that all or even many models are *wrong*. By design (Simon, 1996), models are artificial representations of the real world, and are intentionally parsimonious to avoid clutter and to expose essential properties of the areas of interest. Failure to recognize what is missing is indeed a wrong use of the model. Specifying the boundaries of the model may prevent this error, and avoid a perception on the part of the model's users that it may be flawed and therefore unacceptable, and to encourage use of imperfect models that are far from wrong.

2.3.2 Interpretation and hermeneutics

The value of a model as a planning instrument lies in its acceptance by stakeholders. Contessa (2007) proposes that epistemic representation should be assessed always from the point of view of a given user. It is only in the *interpretation* of the model and its features that the explanatory powers of the model make sense to any one person. Feinstein and Cannon (2003) note the merits of hermeneutic validation, an overall agreement between the model's features behaviours on the one hand and the observer's experience of the real world on the other.

The truth of the model is a measure of alignment of phenomena in its artificial environment, both created at design time and inferred during experimentation, with evidence of corresponding phenomena observed in the real world (Contessa, 2007). This corresponds to the concept of validity usually referenced in the literature on simulation. Distinguishing the alignment of *deduced* phenomena from those built into the representation through the thematic analysis phase is essential to the model's explanatory capacity; comparing the foundational representations with the evidence on which they are based is tautological.

One of the issues to be addressed in models such as that contemplated in this research is that many of the variables and parameters are unknown or can only be estimated particularly in the initial steps of evaluating scenarios. A team of researchers at the RAND corporation (Bankes, 1993; Bankes and Lempert, 2002) use an approach of robust reasoning combined with agent-based models to deal with contexts characterized by deep uncertainty. In their work on environmental planning, confronting questions and strategies whose consequences would not be known for over three decades, they approach solutions iteratively. Scenarios and mechanisms are proposed by domain experts, in this case environmental scientists, to guide the configuration and specification of adaptive representations of environments. The results of the simulated model runs are expressed in very coarse, directional terms, intentionally avoiding precision and accuracy. These results are then considered by the domain experts, who refine the model design and specification with new scenarios to test for interventions that produce radical shifts in output, and for those that do not. The authors acknowledge that by searching a landscape of potential parameter variations for those that are least sensitive to change, the likelihood increases of selecting policies whose outcome are desirable in spite of the underlying deep uncertainty. Although the initial basic model is unlikely to offer opportunities such as these for scenario expiration, it is notable that the agent-based modelling method facilitate the adaptive behaviour that is key to the RAND method.

2.3.3 Verification and validation

Several authors review approaches to validating models with particular reference to simulations (Barlas, 1996; Marshall *et al.*, 2015a,b). The task is typically broken down into two stages, one of verification that checks that the representation is correctly described (Grimm *et al.*, 2006, 2010; Railsback and Grimm, 2006; Winsberg, 2017), and the second as validation (Marshall *et al.*, 2015b) in which the correspondence between the representation and the target is assessed. Nersessian and MacLeod (2017) argue that both concepts are theoretically the same, but for practical purposes, if only to expose them as distinct steps along the deductive pathway, it is useful to retain the distinction.

A inventory developed by Sargent (2005) is referenced by several researchers (Esensoy and Carter, 2017; Esensoy, 2016, for example), and reproduced in Table 2.2.

Table 2.2: Selected validation tests suggested in Sargent (2013)

Validity test	Specification
Animation	The model's operational behaviour is displayed graphically as the model moves through time
Comparison	Various results (e.g., outputs) of the simulation model being validated are compared to results of other (valid) models.
Event validity	The 'events' of occurrences of the simulation model are compared to those of the real system to determine whether they are similar.
Face validity	Individuals knowledgeable about the system are asked whether the model and/or its behaviour are reasonable.
Predictive validation	The model is used to predict (forecast) the system's behavior, and then comparisons are made between the system's behavior and the model's forecast to determine if they are the same.
Traces	The behavior of different types of specific entities in the model are traced (followed) through the model to determine if the model's logic is correct and if the necessary accuracy is obtained.
Sensitivity Analysis	This technique consists of changing the values of the input and internal parameters of a model to determine the effect upon the model's behavior or output.
Historical data	Several replications (runs) of a stochastic model are made to determine the amount of (internal) stochastic variability in the model.

2.3.4 Boundary conditions

There are limits to what models can contribute to the planning and implementation of reform, and they are the limits of the underlying theories. Whetten (1989) points out that theory contributes essentially to an understanding of the structures (the *what*), mechanisms (the *how*) and dynamics (the *why*) of the domain of interest. However it must always qualify the extent (the "who", "when" and "where) to which that understanding may be applied with any certainty. Quoting Busse *et al.* (2016), " The Boundary Conditions function of a given theory depicts the accuracy of theoretical predictions for any context given a certain structure of the theory. As such, Boundary Conditions describe the generalizability of a theory across contexts."(p. 31).

Boundary conditions extend the *who, what* and *how* of a theory by specifying the extents beyond which the theory as stated may not apply. The generic model is in a sense a theory of healthcare in that it associates concurrent changes in dependent variables with changes in independent variables both endogenous and exogenous.

Model accuracy

The condition that most fundamentally specifies the boundaries of a model is the expected accuracy of its outputs. Frigg and Nguyen (2017a, p. 53) argue as follows:

> "We call this the problem of standards of accuracy. Answering this question might make reference to the purposes of the model and model user, and thus it is important to note that by accuracy we mean something that can come in degrees and may be context dependent. Providing a response to the problem of accuracy is a crucial aspect of an account of epistemic representation."

This reasoning addresses a key consideration in the development and application of scientific models. Models, by design, are limited representations of the real world. Their acceptance depends on the degree to which their results are relevant to the real world. At all times, therefore, their limitations as to scope and accuracy should frame their interpretation, as both theoretical and operational tools.

2.4 Answering the three questions of design, theory and evaluation

Though the questions are layered, the premises in the introduction implicitly uncover a fundamental question:

> if solutions to the challenges of healthcare are to be found in a systems model that would answer *what if?* questions, *what would that model look like?*.

The three research questions that flow from that fundamental question are:

- *how to design (and build) the model?*,
- *how to build the appropriate theory of healthcare?*, and
- *how to evaluate and assess the results?*

The questions embedded within each of these are of two groups: those for which answers are already available and those to be answered using the methodology of this research. Answering the first group begins in the following chapter.

2.5 Chapter summary

This chapter sets out the questions posed in the research and answered in this dissertation. The design question asks how a model can be designed and developed to meet the theoretical and practical requirements of a healthcare system . This leads to searching for theoretical foundations for healthcare as a system. A third question assesses the quality of the answers to the first two.

Chapter 3

Literature: Representations, models, systems and healthcare

This chapter reviews the literature in four domains (i.e, existing models, theories of models, theories of systems and the constructs of healthcare) on which this research is founded. It begins with a review of published models of healthcare systems, at several levels and from various perspectives. That review both identifies progress in the expanding capabilities of the modeling approach, and warrants the claim at the heart of this research that a whole system model of healthcare has not yet been realized. The remaining sections of the chapter review theories and constructs in three domains essential to the methods applied in constructing the model in this dissertation. A consolidated review of models in science provides a framework for constructing explanatory models; the literature of systems science provides a taxonomy and language with which to describe systems. Crucially, a review of the literature of healthcare policy and economics provides abundant empirical data that can be assembled as a coherent construct of healthcare as a circumscribed system.

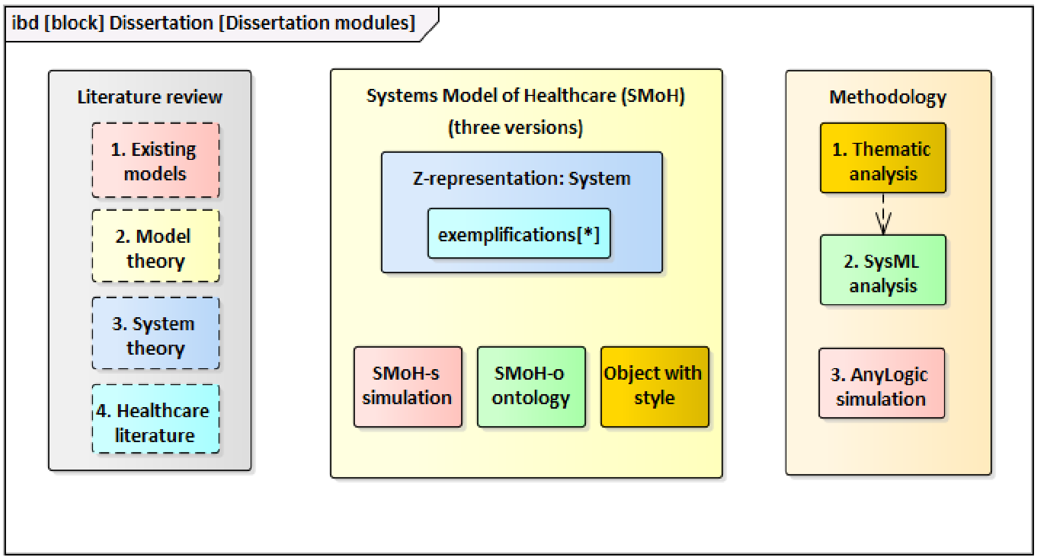


Figure 3.1: The literature review provides the foundations on the systems model of healthcare is developed (Author's own).

The method of each review was chosen to realize its particular purpose.

As a conventional scan of previously published results, the *review of existing models* was broad and inclusive. On the other hand, the *review of the literature of models in science* emanated from a recently published compendium of chapters authored by scholars whose previous works have been widely cited. The *literature on systems science* is diffuse, due in part to ambiguous use of the word *system*. An initial keyword searches produced references to research findings and opinions across a many domains and disciplines. However, a recurring set of citations emerged across this literature. Following a *snowball* process, a limited collection of seminal articles emerged. Finally, the *review of the healthcare literature* in this chapter was conducted as a preliminary scan to expose a dataset suitable for thematic analysis as a first method in the three stage methodology described in chapter 4.

Each of these approaches to review is described in greater detail in the respective sections of the chapter.

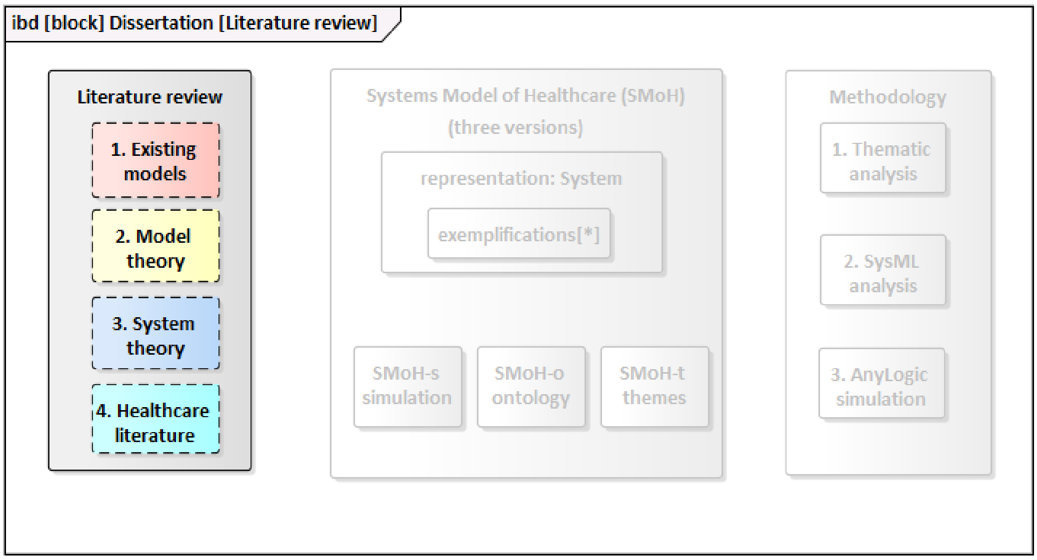


Figure 3.2: The literature review exposes theory, constructs and empirical data in four domains (Author's own).

The research methodology relies on support in four domains for the construction of the systems model of healthcare. The schema in Figure 3.2 recurs in various forms throughout the following chapters to map the steps towards developing the Systems Model of Health – SMoH. In this version it indicates the four foundational domains in the literature.

As an essential function of a dissertation's literature review, *existing models, both of healthcare and of broader economic phenomena,* are discussed both as background and as exemplars whose boundaries may be extended as scaffolding for the systems model developed here. The expanding corpus of contributions to *model theory* in the philosophy of science provides accounts on which to base the design of the model itself as a sound representation, serving an explanatory purpose. The review of *systems theory* describes patterns of relationships and events, exposed as abstractions, show how sets of elements linked in a shared context behave as a single entity. Finally, the *healthcare literature*, as a corpus of domain expertise validated by peer review, is reviewed as a wide and diverse source of empirical data from which to infer essential constructs and mechanisms for representation.

3.1 Existing models of healthcare and the economy

The first dimension of the literature review surveys models of healthcare, identifying various types and categories of models discussed by scholars, and examining instances of models already implemented. The intent of the review is to gather descriptions and analyses of models rather than to evaluate post hoc each one's performance or validity. These implemented models are assessed to examine their boundaries and the types of questions they are capable of answering. This serves two purposes. It tests the assertion in this dissertation that few models are found that represent healthcare as a whole system dynamically and causally. The assessment also reveals constructs used in these models to explain already how aspects of healthcare systems work. The new model developed in this dissertation incorporates these approaches where possible, and benefits from understanding their limitations where necessary.

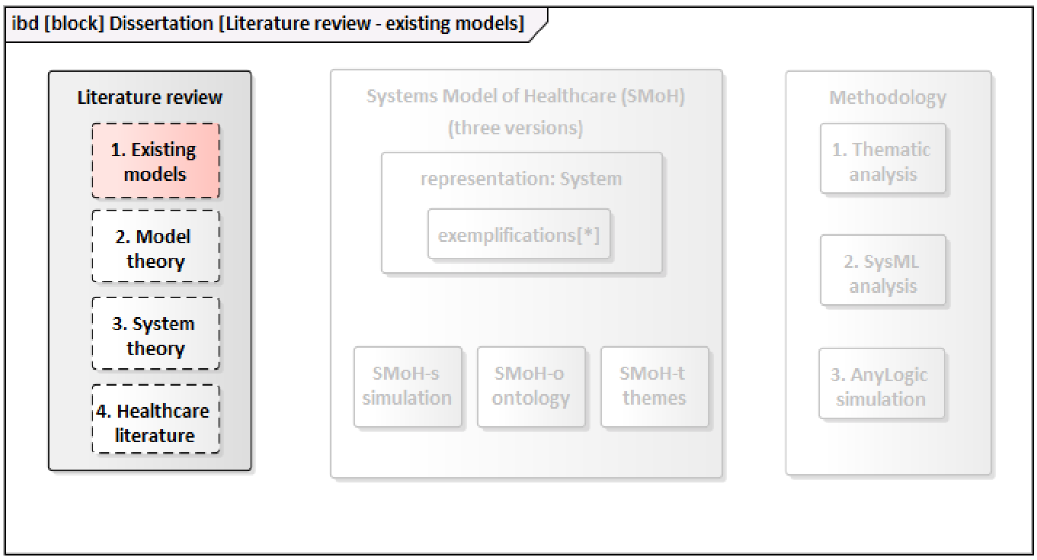


Figure 3.3: Existing and potential models were identified in the first stage of the literature review (Author's own).

Models are found in several categories: conceptual frameworks, statistical models, and a variety of simulation models (e.g., discrete event simulations (DES), system dynamics (SD), microsimulations, and agent-based models (ABM)).

3.1.1 Method of review of existing models

The review of literature on healthcare models was conducted primarily using keyword searches. Because the words *model* and *simulation* are used widely and in many contexts, it was necessary to limit the searches by requiring qualifiers including *healthcare* and *economic*. Searches were conducted naming known simulation methods including *discrete event, system dynamics*, *microsimulation* and *agent based*. Additional material was located by following secondary references cited in articles previously selected for review.

3.1.2 Statistical and econometric models of healthcare

Many of the models in the healthcare literature apply representations adapted from mainstream statistics and econometrics, given the prevalence of comparative studies in the areas of both health politics and health economics where quantitive findings in the latter either corroborate or are explained by the findings in the former. Most studies followed a few familiar patterns. A representative sample is reviewed here, along with some articles of exceptional relevance to the design question at the centre of this research.

General linear regression models are used in a substantial number (in excess of fifty) of the health economics and policy studies retrieved in the search. Without doubting the appropriateness of their methodological choices, it appeared that many studies omitted logical justification for their use of their production function formulation in representing the relationships among variables of interest. These models are therefore not included in this review.

Health sector databases maintained by the Organization for Economic Development and Cooperation (OECD, 2017, 2018) support many comparative studies using secondary quantitative data gathered from over 20 member countries, with some data sets extending back over five decades. As an organization, the OECD has published a number of working papers examining healthcare trends, supporting planning and identifying relationships to guide the development of policy. In addition to the quantitative insights that they provide, the papers also provide representations of healthcare systems that can be incorporated into a more complete systems model.

A foundation for a consistent quality indicator framework has been developed (Kelley and Hurst, 2006), but has not yet been widely adopted in the data submissions of member countries. A preliminary implementation of the larger framework focuses on measures of quality on a matrix of effectiveness, safety and responsiveness assessed on a scale healthcare needs ranging from staying healthy to coping with end-of-life.

Benchmarking is advocated as an approach to evaluating relative efficiency among selected countries (Häkkinen and Joumard, 2007). The evaluation can take place on any one of three axes – across an entire system, differentiated by disease, or differentiated by subregion. Joumard *et al.* (2008) examine the determinants of health outcome as represented by life expectancy and avoidable mortality. They evaluate the merits of cluster analysis in differentiating outcomes based on different characteristics of the various healthcare systems, concluding that the approach offers little extra insights. They also conclude that life expectancy and adjusted life years, while they have shortcomings, are still the preferred measures of overall health status.

A model for planning of health human resources (Ono *et al.*, 2013) represents inflows and outflows of clinical professionals, and the changing demands for their services that result from population and technological changes.

In many of these economic studies, the functional relationship among variables is not often addressed in detail. The authors use common econometric approaches that focus on identifying and quantifying the impacts of independent variables on a dependent variable of interest. Their findings rely on the extent to which the data is inspected and cleaned and on the steps taken to apply appropriate statistical methods that quantify uncertainty.

Less attention is directed to the underlying functional relationship posited among the variables in these regression models. The Cobb-Douglas function (Douglas, 1976) and its variants, e.g., translog function (Kim, 1992), are commonly applied, although the rationale for their choice is rarely reported. From a computational stand point, there is merit to the choice – algorithms and heuristics have been developed in many statistical analytical packages enabling the estimation of impact and the quality of those estimations. The underlying production function has been refined and extended to support estimation of (in)efficiency for instance (Aigner *et al.*, 1977; Battese and Coelli, 1992; Charnes *et al.*, 1978). Jacobs (2001) and Jacobs *et al.* (2006a,b) for example use this approach in comparing and ranking healthcare within the healthcare system in the UK.

Smith and Yip (2016) note that the publication of seminal report by the World Health Organization (WHO, 2000) was followed by a number of comparative studies that examined several indicators thought to effect variation in efficiency among countries. The model itself examines healthcare from several perspectives – the nature of healthcare, measures of performance, the organization of services and the resources required to support them. In particular, it includes equity in payment and the role of government in protecting the public interest. A report of commissioned studies accompanies the report, ranking the performance of the healthcare systems of 191 countries, using a composite measure of performance, based on disability adjusted life expectancy Evans *et al.* (2001). The findings have subsequently been challenged on methodological grounds (Gerdtham and Löthgren, 2001; Hollingsworth and Wildman, 2003; Navarro, 2000). The main concern is with the choice of a composite index, although the application of stochastic frontier analysis (SFA) as a estimator of efficiency is also seen as problematic (Greene, 2004). However, the methodology is later applied with different independent variables drawn from the OECD database of health indicators by Wranik (2012) whose model suggests that physician payment is a significant determinant of efficiency, at least as measured by life expectancy at age 60. That work is extended by Hernández de Cos and Moral-Benito (2014) who include additional categorical healthcare system variables previously observed and reported by Paris *et al.* (2010). This latter study surveys 29 countries to calibrate a broad range of structural attributes in the respective healthcare system, including extended health insurance, types of healthcare providers, and modes of payment. The study provides useful insights into both the underlying structures of a wide selection of healthcare systems, and the variation in parameters that account for the observed heterogeneity among them.

3.1.3 Healthcare frameworks

Frameworks explain healthcare systems by identifying essential constructs and the connections among them. As models, they are qualitative and static. As instances of their explanatory capabilities, Papanicolas and Smith (2013) show how known frameworks explain boundaries, purpose and functional architecture of systems, and how the relationships between that architecture and performance. Eight of the most prominent frameworks are reviewed below, in the order of their publication date.

Aday and Andersen (1974)

This framework explains how health policies influence access to healthcare services. Financing, human resources and organization determine the characteristics of the provision system, which develops with a view to the characteristics of a population at risk. These factors result in utilization and levels of satisfaction. Each of these factors, as outcomes or determinants, are further described by the system's inherent properties such as policies regarding finance education manpower and organization, or the resources and organization that contribute to the characteristics of a health delivery system. The framework identifies consumer satisfaction as a combination of convenience, costs, coordination, curtesy, information and quality while the utilization is described in terms of type, site, time interval and purpose. The framework identifies mechanisms at a high level. Behaviours can be inferred from relationships among the constructs, but the representation of dynamics and causality is limited to constant conditions only.

Frenk (1994)

Blocks represent five key domains of a healthcare system in this framework. It distinguishes five components within the generic healthcare system, with the population, and collective healthcare providers each identified as organizations, resource generators as a separate group and then other sectors that contribute to healthcare as a fourth group and with the state as a collective mediator among those four. The relationships among these components are distinguished on the one hand as services and as flows of information and payment, while on the other hand the state exercises control through regulation of the remaining four and competition rules determine relationships between healthcare providers on the other sectors. This framework reflects the wholeness of healthcare and identifies flows among the components. In that respect it meets two of the three requirements identified; mechanisms that might indicate causal relationships are only likely referenced.

Murray and Frenk (2000)

A healthcare system is represented as a combination of five key functions - system design, performance assessment, priority setting, advocacy and regulation. The framework exposes the degree to which those functions are integrated among the participants in the system. Structurally, it focuses primarily on the provision and regulation of care, and assigns the elements as groups within each of the identified functions. As a framework it helps identify the consequences of variation of structure across the functions. Dynamics and causality can be inferred but are not explicit in this model.

Hsiao (2003)

This framework conceptualizes healthcare around two groups of properties structured as inputs (means) and outcomes (ends). It explains variations in outcomes, as observed in several healthcare systems, in terms of diverse approaches to the structuring of means, such as financing, organization, methods of payment, regulation and persuasion. Combinations of these factors appear to determine some outcomes such as average level of health status, risk protection and consumer satisfaction. The model represents the dynamics and causality of healthcare systems to a limited degree but only by a generous interpretation can it be considered representative of the whole system. The framework is a useful guide to some mechanisms that explain differences in outcomes across healthcare systems. Its scope is comprehensive if somewhat sparse, and it is static.

Atun and Menabde (2008)

This framework places the healthcare system in the larger context of other influences – social, technological, economic, legal, demographic and political. The system itself is composed of elements representing financing, regulation, allocation and provision - that influence key measures of outcome including equity, efficiency an effectiveness through the mediation of equity, choice, efficiency and effectiveness. The framework includes properties across the whole system, at an aggregate level. The relationships are logical only; they do not represent the dynamics of behaviours or events.

Roberts et al. (2002)

This framework identifies essential constructs in healthcare systems, distinguishing the important outcomes, and the variables that have the potential to influence them. Operation of the system is interpreted with five *knobs* representing the financing, payment, organizational, regulatory and persuasive interventions available to stakeholders to modify health status, financial risk protection and satisfaction. This model represents the wholeness of healthcare in that it addresses the respective roles and behaviours of people, providers and funders of services, although it does so at a high level only. Relationships are described in static terms, and explanation of dynamic and causal behaviours are limited.

Wendt et al. (2009)

This framework is based on a typology to support the comparison of healthcare systems. Using *regulation*, *financing* and *provision* as fundamental properties, it distinguishes permutations of the three as types that vary in the degree to which they are oriented to the state, to society and to private enterprise. The author asserts that the taxonomy helps distinguish the differences among observed healthcare systems. Transformations over time might be explained in this framework by applying change concepts such as those discussed later in

Hall (1993). The model focuses primarily on the structures and components of governance, with limited reference to measures of health status or of cost.

Marmor and Wendt (2012)
This framework is designed to support comparison of different healthcare systems. It portrays a system of serially connected blocks that reach from monetary inputs (expenditures) that facilitate real inputs (personnel and resources), through mediating real outputs (processes and utilization), to outcomes (health status and satisfaction). The flows through these interconnected components are influenced by institutions and political actors, and by healthcare regulations. The model explains differences among healthcare systems, but does not offer insights into the evolution of systems, and structurally it represents healthcare at a high level only.

Each of these frameworks, spanning four decades, contributes to the understanding of how elements of healthcare systems interact. Individually, they include structural, functional and operational perspectives. Although none simultaneously meets the collective criteria as whole system, dynamic and causal representation, every one provides insights and constructs that can contribute to developing a model that *does* meet the criteria.

3.1.4 Simulations in the general literature

The term *simulation* is commonly applied to models that explicitly represent changes in state over time (Nersessian and MacLeod, 2017). They are dynamic by design, with behaviours that may be continuous or episodic.

In a review of the academic literature, Brailsford *et al.* (2009) report that simulation and modelling has been applied in diverse healthcare domains including planning, finance and public health. During the reporting period, which extends from 1952 to 2007, statistical analysis and modelling were used most predominantly, with simulation modelling reported as the primary method in fewer than 25% of the articles. The majority of the these used discrete event simulation (DES). Six of these also included system dynamics methods (SD) and a further six used SD alone.

This result is not surprising since the rapid improvement in computer hardware and software in the decades spanning the turn of the millennium has provided opportunities and facilities for more advanced methods. Many of these studies are initially presented at *WinterSim*, an annual meeting of operations research professionals sponsored by the Institute for Operations Research and the Management Sciences (INFORMS). Tolk *et al.* (2017) review presentations across all domains in operations research in the earlier years of the conference, while Arisha and Rashwan (2017) review more presentations at over the past two decades, noting the increasing use of SD, and more recently of agent based models (ABM) and of combinations of these methods. Macal and Kaligotla (2017) model the emergence of social simulation, and of healthcare simulation in particular.

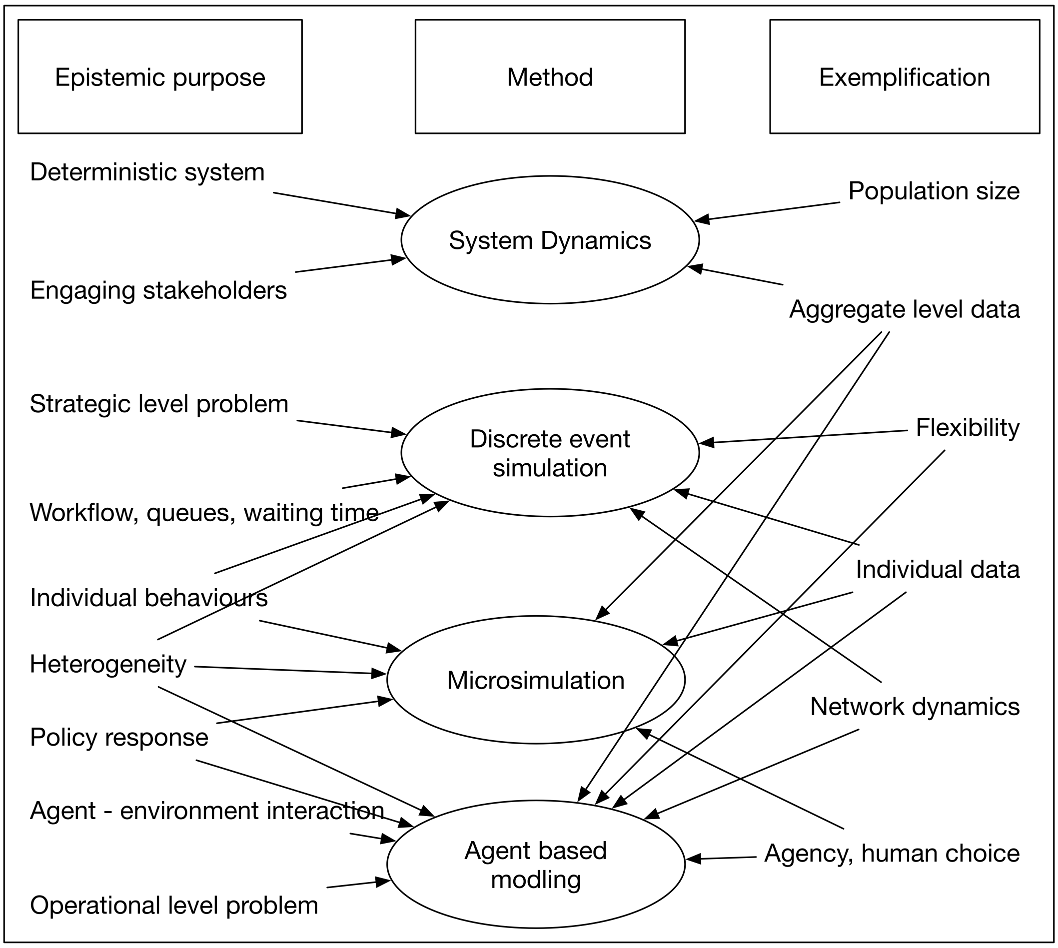


Figure 3.4: Choice of method depends on epistemic purpose of the model, adapted from (Marshall, 2015)

Marshall *et al.* (2015b) report the findings of a task force convened by the International Society For Pharmacoeconomics and Outcomes Research (ISPOR) to examine best practices in the development of simulations with reference to healthcare and to pharmaceutical systems in particular. Figure 3.4 has been adapted from their work and has been extended to include microsimulation as an available simulation option. The task force acknowledges that the choice of method is determined by the constructs and variables in the real world that are to be exemplified in the model, and on the structures of interest within the model itself. Computational complexity is not addressed in the report. The task force (Marshall *et al.*, 2015b) provides guidance on the choice of dynamic simulation most appropriate to a given problem context.

The SIMULATE checklist of best practices relate to overall process, assuming the knowledge resides with experts and approach verifying/validation against agreed criteria. (This acronym prompts consideration of key dimensions of a modeling undertaking: *Systems*, *Interacations*, *Multilevel*, *Understanding*, *Loops*, *Agents*, *Time* and *Emergence*.)

3.1.5 Discrete event and process models

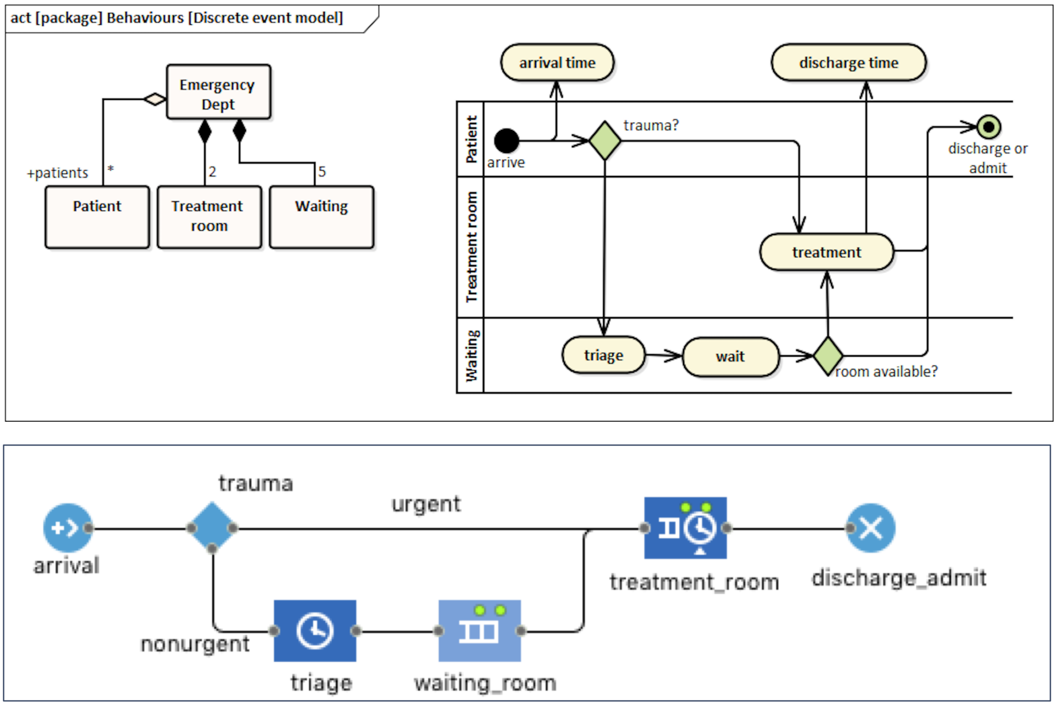


Figure 3.5: Discrete event simulation as system entities and activities and as process stages (Author's own).

Discrete event simulation (DES) answers questions about sequences and processes (Robinson *et al.*, 2010). An event is defined in subsection 3.3.8 as "a change in state in any system that produces a change in state in another system." A DES implements a representation of systems where these changes occur in discrete time (rather than continuously as is seen later in system dynamic models).

Figure 3.5, for example, shows an emergency department (ED) as a simple system (in the upper left quadrant) composed of a waiting room and a treatment room and associated with patients who move through the ED. The activity diagram in the upper right quadrant depicts the sequences of events and actions as any patient arrives for presents for care. Patients suffering trauma require urgent care and are admitted immediately to the treatment room. Other patients register with the triage nurse and wait until the treatment room is available. For operational purposes, the time of arrival and discharge are noted. The process diagram in the lower portion of the figure translates the various stages of the activity diagram as choices (*trauma, room available*), processes (*triage, treatment room*) and delay (*waiting room*).

The application of DES in healthcare has grown five-fold in the first decade of this millennium according to Günal and Pidd (2010). The method has been used primarily in areas involving queues and scheduling, particularly in emergent and urgent settings (emergency departments, ambulance services) and in the sizing and staffing of inpatient care units. Studies are specific to individual facilities and to units within them; there is little evidence to suggest that they have been adapted to other settings.

Discrete event simulations are typically implemented on software platforms that were developed in the early years of personal computers and have been adapted to avail of the graphic and processing capabilities of advancing operating systems. However, many still retain an underlying architecture built around the queuing constructs of process flows. In the interim, other approaches - including agent based models in particular - have evolved to incorporate these constructs as byproducts of their underlying architectures (Siebers *et al.*, 2010). Over the past decade, discrete event simulations of healthcare systems, particularly at the broader levels of networked organizations and of regional systems have been subsumed into *multi-paradigm* representations, which are addressed below.

3.1.6 System dynamics

System dynamic models focus on the rates at which quantities change, and on how they accumulate or dissipate as a result. They implement the constructs originally developed by Forrester (1958) and described later in subsection 3.3.8. Systems structures are specified as flows and stocks respectively and represented graphically using a unique system of symbols.

For greater insight into the how dynamic systems can be described, Figure 3.6 illustrates an example of a systems dynamics model of an epidemic infecting a population. One of the major concerns in an outbreak of an infectious disease is to anticipate as far as possible the spread of infection as it moves through communities by managing contact among two groups - people currently infected and therefore infectious, and people who have not yet been infected and are therefor susceptible. Therefore aggregate quantities are observed in the population as a whole.

The block definition diagram (BDD) in the uppermost panel of the figure shows that although the infection status relates to individual people, the variables in question are properties of the overall system, which is the population

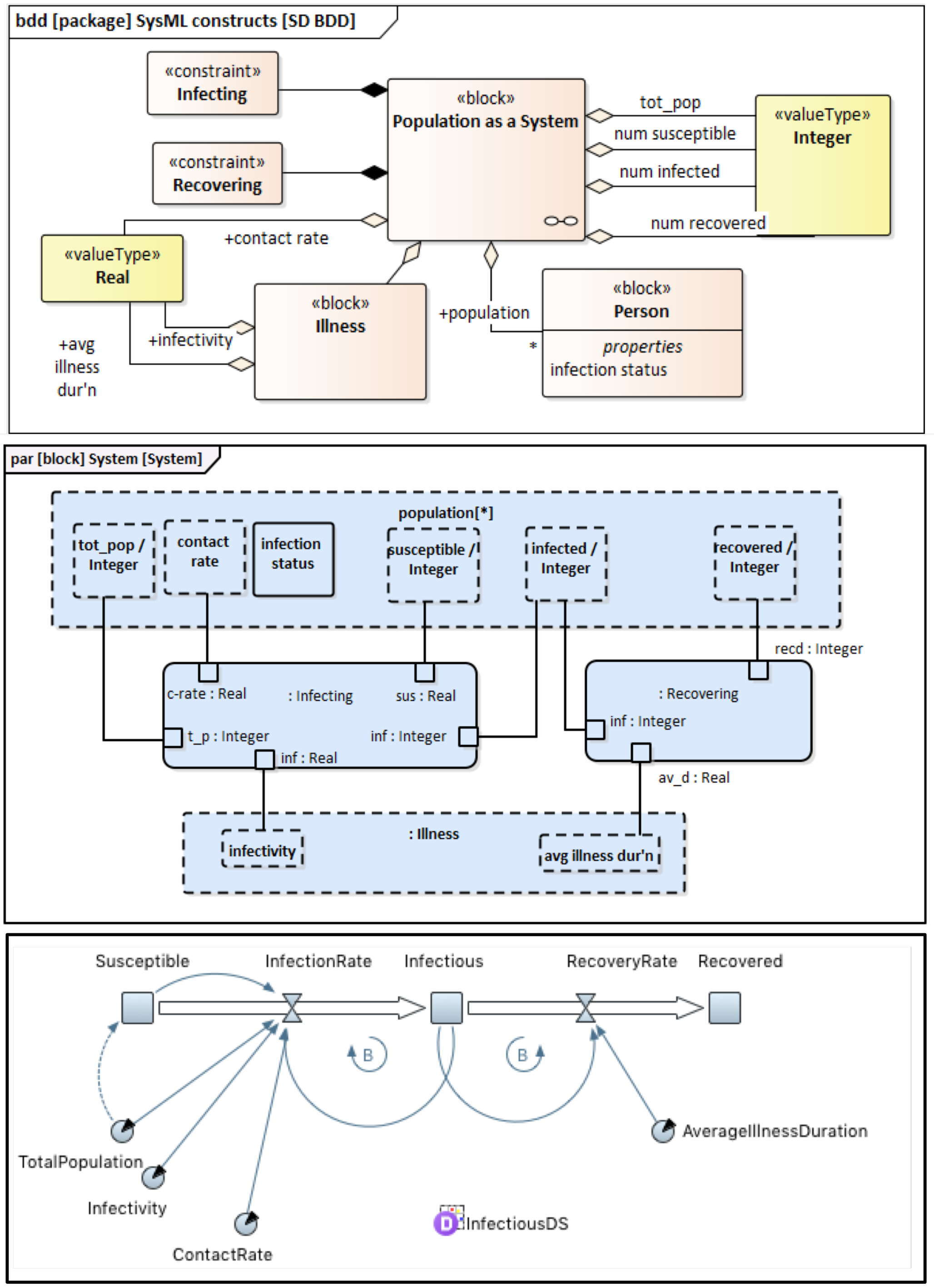


Figure 3.6: System dynamics (SD) simulations implement entity variables as stocks and flows, causally related (Author's own).

as a whole. The same diagram depicts the infection rate and the recovery rate as properties of the illness associated with the infection while the contact rate is a property of the population as a whole. The BDD also includes constraint blocks that specify a relationship among some variables in determining the rate at which people become infected and recover. The parametric diagram in the centre panel of the figure depicts the connections among the variables as the functional relationship defined within the documentation of the constraints.

In the lowest panel, the system is represented with the characteristic stock and flow symbols of Systems Dynamics. The loop symbols at the centre show that increases and decreases in the numbers of infected individuals are associated with corresponding changes both in the rate of infection and in the rate of recovery. In the scenario depicted, the causal loops indicate that both mechanisms are reinforcing. The extent of the outbreak is limited only by an assumed immunity to further infection among those who have recovered.

This example reveals the three main features of SD models: (i) actors are represented in aggregate, (ii) behaviours (in aggregate) may be specified in closed form, and (iii) feedback of variables may result in nonlinear behaviours.

In their previously cited review of the literature, Brailsford *et al.* (2009) report that systems dynamics modelling has emerged as a method of choice in healthcare. The applications were used mainly in the areas of strategic planning at an institutional level and in operational planning at a departmental level. Lane and Husemann (2008), for instance, report the use of systems dynamics in mapping acute-care patient flows in selected NHS hospitals in support of planning exercises carried out by clinical professionals. Rashwan *et al.* (2015) report a similar exercise in selected hospitals in the Irish healthcare system. A study in the Netherlands (Logtens *et al.*, 2012; Pruyt *et al.*, 2011) describes the use of system dynamics to examine the effect on system capacity in that country due to the combined mechanisms of aging and of immigration. The model continues to be used for policy planning purposes at a national level. A study in Singapore (Ansah *et al.*, 2014, 2013) report on similar challenges, assessing the need for increased physical capacity and long-term care, and for greater numbers of clinical professionals to meet the needs of an aging population, and to replace clinicians reaching retirement age. In a recent study, Esensoy and Carter (2017) use system dynamics, and causal loop diagrams in particular, as a planning instrument to support policymakers in allocating resources among various sectors of regional healthcare systems, noting the interdependence of demand and capacity between acute-care, community care, rehabilitation and long-term care.

The boundary conditions vary in these implementations of healthcare system models using system dynamics. Some limit the scope to an institutional level, and to the mechanisms of provision. These models address patient outcomes incidentally only. Others are systemwide, with limited attention to costs, or to the distribution of impacts on individual health status. The strength of these models is in the representation of healthcare system dynamics, and in the opportunities to evaluate selected scenarios to measure and assess sensitivity to policy interventions.

3.1.7 Microsimulation models

In representing social systems, microsimulation distinguishes individual people as members of the system. The properties and states of each individual are maintained as a database, to be acted upon by rules of various types, depending on the specifics and context of the model's purpose. This approach distinguishes microsimulation from the earlier models that use one or a limited number actor elements, in economics, the so-called *representative agent*, as representative of the population. The nature of the rules applied to the data produce two types of model (Li and O'Donoghue, 2012a,b; Li *et al.*, 2014). In static models, the rules are typically in the form of policy options – revisions to tax codes, for example – to be applied as distinct scenarios using the current policy as a reference state, and the proposed changes as comparators. The changes are assumed to take effect immediately.

The second, dynamic type of microsimulation represents ongoing changes in the state of individuals in response to timed events either endogenous to the individual or exogenously in the common context in which the individuals are assumed to exist. Pension planning, for instance, uses this approach, where aging and employment are relevant to the individual's state, and the financial outlays by government are of interest over extended periods of a proposed programme (Li and O'Donoghue, 2012b). Similar approaches are applied in clinical care (Niessen *et al.*, 2000; Rutter *et al.*, 2011).

In Figure 3.7, microsimulation represents a simple example of a health related system. The context once again is illness episodes. The primary feature of these models is the manner in which the essential state of every individual actor is maintained while under the external influence of the illness and its variables. The heterogeneity among the actors is aggregated at the system level, unlike the system dynamics approach where, at best, the heterogeneity is bounded at the level of cohorts. The upper left panel depicts the system as comprised of individual actors, each of whom changes state when illness is encountered, and again after a period of recovery; a state diagram in the upper right panel represents those changes. In the lower panel the structural

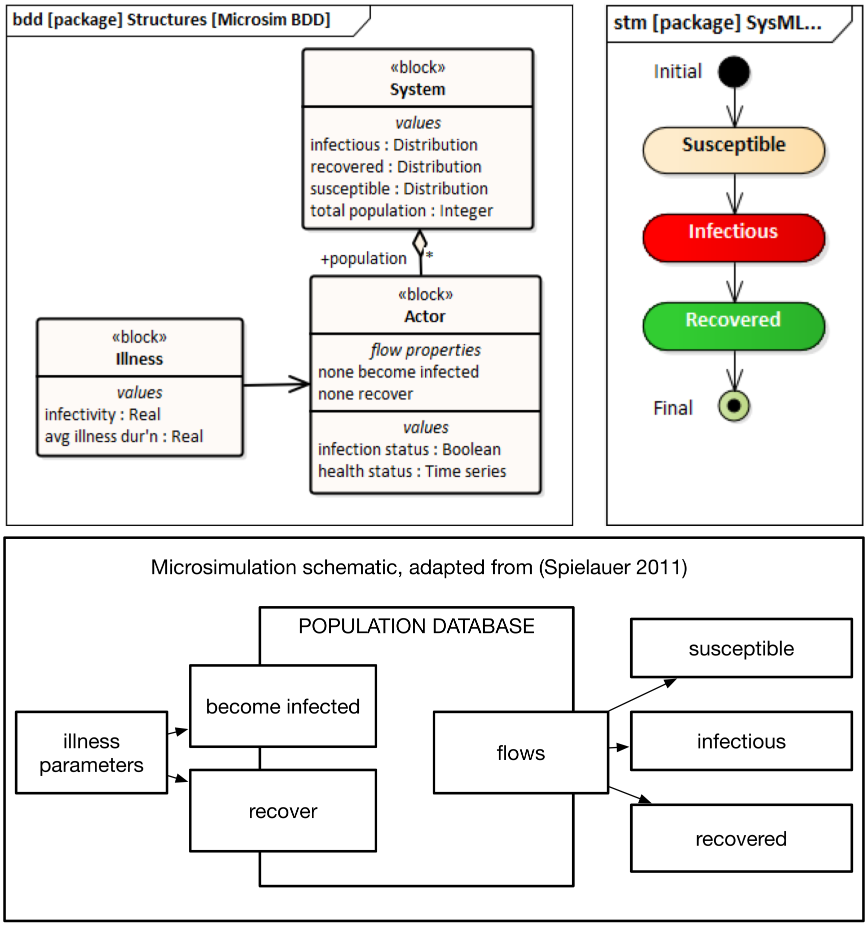


Figure 3.7: Microsimulation models represent the heterogeneous states and reactions of individuals as distinct members of a social system (Author's own).

relationships among the data elements and the behaviours are shown in a style more commonly used in the literature on microsimulation.

With an interpretation of *policy* oriented to system organization at a public and political level, Spielauer (2007) provides a general overview and inventory of healthcare models. Most have been developed in countries in which government plays a substantial role in the regulation and, in particular, the funding of healthcare. Astolfi *et al.* (2012a,b) report a broader and more recent survey of countries in which microsimulation models have been used to estimate future trends in healthcare expenditures. The models are constructed to reflect the idiosyncratic structures of the host countries. It is not evident that many are in current or routine use.

Keyword searches on "microsimulation", "health" and "policy" produce research articles with a clinical orientation while others address expenditure, funding and governance. Rutter (2017) clarifies that "Microsimulation models for health policy are a type of decision analytic model that describe disease processes by simulating key events that occur as disease develops. Their purpose is to help decision makers identify trade-offs associated with different policy decisions" (p.2). Patient outcome and treatment regimens are the main focus of the research, including assessment of technologies, of treatment approaches and of drugs. Researchers at Statistics Canada, for instance, have developed a layered approach using MODGEN (Spielauer, n.d.) as a modular language, a healthcare related implementation (POHEM) combining database and model (Hennessy *et al.*, 2015; Will *et al.*, 2001; Wolfson, 1994), and applications to specific health issues (Hennessy *et al.*, 2017; Wolfson *et al.*, 2017). As usual with this type of modelling, the focus is on patient outcome. Provision and funding indicators arise typically as variables in configuring scenarios to explore sensitivity to variation.

RAND Corporation developed two microsimulation models of relevance to healthcare policy development. *COMPARE* (Goldman *et al.*, 2004), is a static model, designed to represent the reactions of households and firms to various changes in healthcare policy changes. FEM, the Future Elderly Model (Goldman *et al.*, 2005; RAND Health, 2008), is a dynamic model, based primarily on population projections, that estimates the healthcare needs of elderly people, and the costs of meeting those needs over two decades ending in 2030. The model has been used (Goldman *et al.*, 2013) to estimate the effects of extended life expectancy, and of improvements in treatment techniques that might minimize or eliminate some disease conditions. The two models are complementary in that the dynamic FEM is used to estimate parameters of total future demand and utilization in scenarios implemented in the COMPARE model. Neither model alone can be used to answer "what if?" questions over time, but together they can provide some guidance on policy impact.

Microsimulation models were used to design and evaluate *ex-ante* the Affordable Care Act (subsequently and colloquially known as Obamacare) which began the reform of healthcare systems in the United States in 2010. The models were subsequently applied, although not always successfully, in understanding and estimating the merits of proposed measures to repeal and replace the systems that had been in place. The structures and processes of the reform were based in large part on the Gruber Microsimulation model (GMSIM[1]) (Gruber, n.d.), developed earlier to support a state wide system in Massachusetts. The purpose of the model was to estimate uptake of various types of insurance, either as provided by employment or purchased as individuals. As a secondary outcome, the model was also designed to simulate the behaviour of and costs to firms in offering health insurance to their employees. For the purposes of the federal program, the data for individuals were derived

[1]Formal specification of GMSIM does not appear to have been published in the public domain. The document cited was retrieved from a public archive maintained by the Center for Health Policy & Inequalities Research, Box 90519, Duke University, Durham, NC 27708

from national datasets of demographic, health utilization and employment. Synthetic data sets were developed to represent firms as employers. At the time of development and enactment, the Congressional Budget Office (Congressional Budget Office, 2007) used its own simulation models to estimate the economic and financial impact of the programme. Although the legislation was eventually passed, and some validation was provided by referring to the outcome of the earlier state wide implementation (Gruber, 2011), it is not clear that the model succeeded as an explanation sufficiently compelling to offset ideological and political objections to its mechanisms and projections.

Most of the models cited here use either Structured Query Language (SQL) databases or cell-based spreadsheet methods to observe transitions of individual actors into and out of states of illness; the models estimates volume utilization of services associated with each of those states, and can project forward expenses based on population projections and on observed historical utilization and cost patterns. In that respect, the models are dynamic, although their causal character is limited to one intervention at a time, and the variables of interest limited to financial indicators and occasionally to access.

3.1.8 Agent based models.

Agent based models are similar to microsimulation models in that they represent properties and functions of individual, heterogeneous entities. Table 3.1 compares and distinguishes both types on several bases, as suggested by Singh *et al.* (2016b).

The primary distinction between the two approaches is the capability in agent-based models of interaction among entities, not just of the same types with similar generic features, but with types that are substantially different both in properties and their behaviours. An early model (Epstein and Axtell, 1996) exploits this capability by observing evolving patterns that emerge among collections of simple agents whose only behaviours are to seek and consume a nutrient (Sugarscape). Epstein (2006) extends this approach by observing patterns of behaviour over time in a artificial community of agents representing a tribe as they lived and migrated in an artificial landscape. The observations compare remarkably well with the reported results of anthropological studies of the Anasazi, a tribe of the Pueblo culture known to have inhabited a region of Arizona and whose movements have been traced using archeological findings. These models mark the emergence of entities and activities in complex representations of heterogeneous system.

More recently, agent-based approaches have been used to develop macroeconomic models. The European Union supports the ongoing development of

Table 3.1: Comparison between Microsimulation and Agent Based Simulation

	Characteristic	Microsimulation	Agent Based
1	Origin	Stochastic process	Artificial intelligence
2	Purpose	Projection/validation	Explanation/emergence
3	Research approach	Deduction: aggregating individual units	Induction:behavioural emergence of units
4	Analysis Method	Infer from aggregate to individual	Infer from individual to aggregate
5	Applications	Econometrics, traffic modelling	Social simulation
6	Basic Constituents	Micro units and aggregate entities	Individual agents connected with each other
7	Possible interaction	2 entities	2 or more entities
8	Constituent unit decision process	Probabilistic	Deterministic
9	Number of agents	Higher	Fewer
10	Complexity of agents	Lower	Higher
11	Communication between agents	No	Yes
12	Development of expected output	Built through transition probabilities	Built thorough agent's rule set
13	Agents Properties	Units with provided data and transition rules	Intelligent agents
	Source: Adapted from	(Singh *et al.*, 2016b)	

Eurace, an agent based model of an artificial economy (Dawid *et al.*, 2012). Another macroeconomic model is being developed (Dosi *et al.*, 2009; Fagiolo and Roventini, 2016), putatively as a more useful alternative (Caiani *et al.*, 2017; Fagiolo and Roventini, 2012, 2016) to existing Dynamic Stochastic General Equilibrium (DSGE) models currently used in economic policy planning (Smets and Wouters, 2003).

Few agent based models have been developed for healthcare systems broadly defined. Those that have been developed focus on representing infections and epidemics (Aleman *et al.*, 2011; Epstein, 2009; Epstein *et al.*, 2008) where the interactions among people who are infectious or susceptible to infection can be readily represented with simple configurations of agents and linkages. Agent based models of social choice are emerging in the social science literature (Padgham *et al.*, 2011, 2015; Singh *et al.*, 2016a).

3.1.9 Summary of existing healthcare models

Research that develops theories of healthcare is well served by models, but few of those available are capable of representing healthcare dynamically and causally as a single system. Econometric models that allow estimation of impacts on health status of variables such as payment mechanisms (O'Reilly *et al.*, 2012b) or physician numbers (Or *et al.*, 2005) use production functions to represent mechanisms that in the real world involve counterfactuals and multiple factors that have in the model are held constant, subjected to an assumption of *ceteris paribus*. Many frameworks address the systemic wholeness of healthcare, but do not represent dynamics and causality well. Simulation models represent dynamics well, but tend to focus narrowly on regions of a healthcare system that are perceived as problematic. Microsimulation captures essential heterogeneities within populations of people providers and payers, but are limited in their range of causal relationships. Other forms of simulation represent actors in aggregate only.

Based on this review, only agent based models offer promise in meeting the three requirements of a reference systems model of healthcare, from a whole-systems view that is dynamic and causal. However,an agent based model has yet to be applied to a healthcare system as a whole.

3.2 Model theory literature

The design question (section 2.1), one the three main research questions in this dissertation, raises subordinate questions in that it refers forward to the literature review. The first of these questions relates to the nature of *scientific* models, asking specifically what they are and how they work. The second one relates to the particular *purpose to be served* by the model in this research, asking in what way scientific models explain and predict. Model theory offers insights into both questions and underpins the research methodology that generates the systems model of healthcare.

3.2.1 Method of review of model theory

This review of models in the philosophy of science literature is guided primarily by a recent handbook reviewing model based science (Magnani and Bertolotti, 2017). There, Frigg and Nguyen (2017a) clarify requirements raised by the primary design question, providing structure to the nature of and purpose of models in general and how they represent their targets. Bokulich (2017) unpacks concepts that account for explanation, and the conditions under which reasoning with a model may be applied to its real world target. Based on this thinking, a schema emerges suitable for adaptation and incorporation in the methodology used in the construction of the systems model of healthcare. Other references were found through a *snowball process*, tracing back through references the threads originating in these works.

3.2.2 Models in science

Models offer insights into scientific domains from three perspectives (Frigg and Hartmann, 2006). First, from a *semantic* perspective, they provide meaning by *representing* phenomena or data. The authors cite as an example the billiard ball model of a gas (where the motions of molecules are represented in an imagined space where the imagined billiard balls collide), or the billiard ball model of the solar system (where the motions of the planets are represented by billiard balls suspended in a different and possibly real space.)

The second, *ontologic*, perspective distinguishes the objects used from the phenomena they represent. It acknowledges, for instance, that the balls in the previous examples are material objects whose properties may be interpreted to represent the motions of gas molecules, and that other objects, e.g., diagrams or mathematical equations, could also be used to represent the same phenomena.

The third, *epistemic*, perspective establishes the model's *purpose*, the objectives to be realized by its users, such as learning, experimentation or projection, for instance.

Frigg and Nguyen (2018) extend these three theoretical perspectives with an account that reconciles the insights of several authors. The theoretical foundations of their account (Frigg and Nguyen, 2017a) are presented here with explanation sufficient only to warrant its inclusion in the methodology.

To motivate those explanations, the section begins with three examples of scientific models.

i) London Underground map

Contessa (2007) uses the map of the London Underground as an example of a scientific model. It is a material *object* – a large static image – that uses graphic symbols and coloured lines – a *style* – to *represent* the underground as a collection of stations and the tunnels that connect them. The representation is parsimonious. The layout only approximates the geographic locations, and differences in elevation are minimally indicated. However, the map, as a model, serves as an *epistemic representation* by answering questions such as "how do I get there from here?" in the model/map so that those answers may be reliably applied in the world of people travelling on trains in tunnels between stations.

ii) Moniac, the Newton-Phillips economic machine

The Moniac (Ng and Wright, 2007), formally known as the Newlyn-Phillips economic machine, is a plumbing model, a physical structure of pipes, valves and vessels connected in such a way that levels of water in various tanks correspond to values of economic indicators of the national accounts. The valves, pipes and vessels are configured to implement hydraulically the behaviours of a Keynesian economy. Changing valve and water volume settings simulates changes in interest rate, monetary policy and investment.

The Moniac is a *model* that, as an *epistemic representation*, using the hydraulic *style* of a plumbing *object*, describes a country's economic state, *representing it as* a Keynesian economy.

Frigg and Nguyen (2018) use the fictional application of an actual model to illustrate their account. The fiction involves government policy makers turning to their own copy of the Moniac machine to find out that an impending precipitous fall in foreign direct investment would have disastrous effects on their national economy in terms of employment and solvency.

iii) Rocket Man, a transit system mobile app

The *Rocket Man* is a mobile phone app developed to support passengers using the municipal transit system in Toronto.

The Toronto Transit Commission (TTC) operates an integrated passenger transportation system of buses, streetcars and subway trains, travelling over city streets and assets owned privately by the commission, on routes past stops and stations. Some routes intersect at some stops and stations, allowing passengers to follow individually suited itineraries. Published schedules estimate events and travel times that are often realized in practice. Planners use records of past events to update published schedules. To the citizenry, the TTC *is* the system.

Rocket Man is a software application, one of millions designed to function within the operating systems of mobile devices. This application has images of toy buses and trams as icons, maps showing stylized roads and rail lines and named highlighted locations on both. The app shows lists of those locations as routes followed by the icon. With suitable configuration it indicates the route associated with a given icon on a given map, and may indicate the location of the icon on the route at a given time. Based on an estimate of the vehicle's speed, the app predicts the time of arrival for the icon at a chosen location.

The app's developers claim that Rocket Man models the TTC with sufficient truth[2] to allow users to plan their travel. It represents (in adequate detail) the complete transportation system as it changes state over time.

[2]The claim is warranted, in the experience of this author.

3.2.3 How scientific models represent

Understanding *how models represent* is vital to constructing a model that will do so. "The first and most fundamental question about a model therefore is: In virtue of what is a model a representation of something else?" (Frigg and Nguyen, 2017a). That understanding relies on three concepts: surrogative reasoning, representation-as, and the use of objects as interpretative devices.

In an extensive discussion of positions taken by various philosophers of science on conditions under which a model is a representation, and what form that model might take, the authors suggest 5 issues that must be addressed in selecting or constructing a model as a representation. They are listed in Table 3.2.

Table 3.2: Required answers in a model-representation

	Issue	Meaning
1	Provide an answer to the epistemic representation problem	what knowledge will be gained from using the model?
2	Take a stand on the representational demarcation problem	the question of how scientific epistemic representations differ from other kinds of epistemic representations
3	Respond to the problem of style	what styles are there and how can they be characterized?
4	Formulate standards of accuracy	how do we identify what constitutes an accurate representation?
5	Address the problem of ontology	what kinds of objects are models?

Source: Adapted from (Frigg and Nguyen, 2017a)

Issue 1 relates to *epistemic representation*, to the way in which learning from one thing represents learning from another, expressed as a particular relationship between features of the two. Issue 2, the *representational demarcation problem*, refers to an unresolved debate about whether representations other than models can meet such a surrogative reasoning condition. Since this research is predicated on the use of a model, the issue is moot for the purposes of the dissertation. However, it does adopt the position taken by Contessa (2007) who asserts that epistemic representation ultimately rests on the interpretation assigned by a user to the phenomena in a model. The issue of interpretation is discussed later in detail.

Issues 3 and 5 distinguish the ontology perspective from the semantic. The authors distinguish the representation (semantic) from the object used to describe it (ontology), where each object uses a particular style (visual, narrative, diagrammatic, physical) as its medium.

Issue 4 is self evident, but is essential in setting and understanding the representative boundaries of the model.

Surrogative reasoning

The first two issues/questions in Table 3.2 include the concept of *surrogative reasoning*. The rationale for using this concept was originally proposed by Swoyer (1991)as follows:

> "We represent things using scale models, road maps, computer simulations, musical notation, Godel numbers, English sentences, smoke signals, and Braille. The diversity of examples suggests that anything can, with sufficient ingenuity and determination, be employed to represent almost anything else, and the uses we make of representations are nearly as varied. Nevertheless, I think that a central point of much representation - one reason why it plays so vital a role in our lives - is that it allows us to reason directly about a representation in order to draw conclusions about some phenomenon that it represents." (p. 450)

In this dissertation, the relationship is specified as *scientific*, satisfying the *surrogative reasoning condition*.

Contessa (2007) extends the surrogative reasoning concept as "an expression. . . to designate those cases in which someone uses one object, the *vehicle* of representation, to learn about some other object, the target of representation." (p. 51) She then incorporates this concept arguing that *valid* surrogative reasoning is a necessary condition for *epistemic representation*. This she clarifies is a matter of *interpretation*: "a vehicle is an epistemic representation of a certain target (for a certain user) if and only if the user adopts an interpretation of the vehicle in terms of the target." (p. 57) She formalizes three conditions that must be met. Considering both the model and the target as specified in terms of sets of elements, of relationships and of functions, a model meets the surrogative reasoning condition if and only if *(iff)*

1. Membership in the set of elements of the model *implies* membership of corresponding elements in the target.

2. Relationships between elements in the model *imply* corresponding relationships among the elements in the target.

3. Functions describing relationships in the model *imply* the same functions describing the corresponding relationships in the target.

Representation and exemplification

The concept of *representation* is elusive but central to models. There is an fundamental difference between a thing, *Z*, that is represented and the construct that represents it. Frigg and Nguyen (2017a) distinguish *representation-of* and *representation-as*. The former is the relationship with thereal world. The latter is a limited set of properties that are highlighted and thought to relevant to understanding that world. A model *denotes* its target in the sense of *representation-of*. On the other hand, a model highlights certain relevant properties and relationships as *exemplifications* when it describes a *representation-as*. This is known as *Z-representation*.

The examples suggest the distinction. The *Z-representation* in a map is the geographic layout of spatial locations and their connections; the parameters in that layout are the exemplified properties that describe the infrastructure of the London Underground relevant to navigating its stations and routes. The *Z-representation* embedded in the Moniac machine is an economy (of the Keynesian variety) in which exemplified variables (keyed, for instance to goods consumed and people employed) are mathematically related and mutually constrained, and are relevant to understanding the consequences of policy change. Rocket Man's *Z-representation* of the TTC is a collection of functional relationships and algorithms implemented in a software programme that update variables (keyed to real time and to real places) interpreted as the properties of interest to users of the transit system.

The next section links the Model and its user by explaining how *objects* expose and describe the properties of the *representation*.

Description with object and style

The *representation*, in the model, as an abstraction of properties, establishes the link between the artificial model and its real world target, a necessary but not sufficient condition for *using* the model to realize its purpose. The *object* component is a base whose *interpretation* constitutes the *representation-as* that describes and exposes it to observation and manipulation.

> "a model represents a target and can be used to perform surrogative inferences about the target in virtue of the fact that the user interprets the vehicle in terms of the target." (Contessa, 2007, p. 52)

The object answers the ontology question – "what is the model?" It does so by using constructs familiar to the user that can be interpreted as constructs in the representation. Graphic images on a material map are interpreted as locations and connections that represent the geography of the London Underground. The settings of valves and the levels of water in the tanks of the plumbing contraption are interpreted by users of the Moniac machine as indicators of savings and income and other measures that convey the economic health of a country. The screen displays of icons and lists, and the display of times and schedules are interpreted by the user of the mobile phone to make choices to run for the bus, or to take a longer but faster route by using connecting journeys on subway and streetcar.

3.2.4 How scientific models explain

Explanation requires a scientific model that includes counterfactual dependencies in its representation, and a justificatory step that warrants the application of the inferences in the target.

To quote Bokulich (2011) directly:

> "...in a model explanation the following three conditions hold: First, the explanans makes reference to an idealized or fictional model; Second, that model explains the explanandum by showing that the counterfactual structure of the model is isomorphic (in the relevant respects) to the counterfactual structure of the phenomenon. This means that the model is able to answer a wide range of "what-if-things-had-been-different" questions. And third, there is a justificatory step specifying what the domain of applicability of the model is and that the model is an adequate guide to that domain of phenomena."(p. 44)

Explanation and Prediction

The distinction between *explanation* and *prediction* has been debated. Troitzsch (2009) argues for a symmetry between the two, with two provisos: that precision of prediction depends on available information about initial conditions, and, further, that, with extrapolation from a detailed recent history of events, some predictions may be made without relying on explanation. According to Douglas (2009), the symmetry thesis allows that the logical structure is the same, the only difference being orientation in time; prediction looks forward, explanations look backward.

Retrodiction is the successful fit to historic data, known as inductive prediction. Many forecasts are of this type (Girosi *et al.*, 2009; Gruber, n.d.).

Regressions using lagged variables or vector autoregression, for instance, are based on an assumption that what has happened in the past will with some consistency happen in the future.

Prediction becomes more problematic when innovation is involved; the answer can no longer rely only on history. It relies instead on known mechanisms to explain what could happen. Contessa (2007) concludes that for the purposes of simulation, explanation and prediction may be treated as equivalent, given that sensitivity can be readily incorporated in the dynamic properties of the model.

Precision and accuracy

In Table 3.2, requirement 4, regarding expectations of accuracy, warrants particular attention. One of the major issues in developing models, and simulations in particular, is that they meet some standard of accuracy. The extensive debates on this topic centres on the degree to which the behaviour of the model aligns with the observed behaviour of the target system. In most cases the behaviours of the model and of the target system are quantitative, and more rigorous tests would apply. This concept treats models not as prediction engines but as scenario generators that can produce a diversity of plausible futures (Royston, 2011).

Counterfactuals

Counterfactuals frame options within which inferences may be made. They relate to a person's beliefs about functional relationships in the world:

> "...a conditional is accepted if the consequent is true after we add the antecedent (hypothetically) to our stock of beliefs and make whatever minimal adjustments are required to maintain consistency. In the indicative case, we simply add the antecedent A as if we received a new evidence that affirms its truth and discredits whatever previous evidence we had for its negation. In the subjunctive case, we establish the truth of A by changing the model itself." (Pearl, 2013, p. 798).

In a seminal treatise on causality, Pearl (2009b) proposes a *do-calculus* in which the effects of changes are assessed when some functions in a model are modified by specified interventions. The essential concept is that the interventions assume that the input parameters are independent of other variables in the system, and that their causal effects are observed as they are held constant at various values over their available ranges.

Bokulich (2017)references the proposition in Craver (2006) that mechanisms are integral to explanation in that they allow capture of counterfactual dependence. They are the behaviours associated with particular entities that produce changes and are causal. In their absence, the change is not produced. Explaining a phenomenon requires reference to the mechanisms that produce it, and this in turn requires identification of the activities and associated entities. The fundamental mechanisms are…

> "…entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions." (Machamer *et al.*, 2000, p.2)

Justificatory step and truth

Explanation – the explanans – either describes a phenomenon - the explanandum – in terms of known laws, or follows a causal chain that ends at the explanandum. One problem with this in practice is that the laws are complex or the chains difficult to observe and follow, so models are used instead. Now the problem is to know not only how explanation works in the model, but that it works in the same way in the real world.

Klein (2005) examines models (in this case, *simulation* models) from competing views. A Popperian falsification position would regard models that have been tested and have not been falsified as "a conjecture that will do for now" (p. 307). On the other hand, a falsified result is simply a motivation to improve the model. From this perspective, and in either event, validation by testing advances the degree to which the results produced by a model may be relied up on by a user. In contrast, Klein asserts that tests of simulations, viewed in light of the Duhem-Quine thesis (Quine, 1951) "cannot be conclusively rejected". She concludes that developers of models (and hence users of a model who are prepared to accept the demonstrated validity of models) are well advised to adopt a Popperian view of model validation. Klein's explicit philosophical examination aligns with a number of pragmatically oriented reviews of model validation (Bianchi *et al.*, 2007; Kopec *et al.*, 2010; Marshall *et al.*, 2015b; Weinstein *et al.*, 2003). All recommend that a model be subjected to testing against observed results, and the degree of alignment be used as a measure of reliability, recognizing that at best every model is intentionally an approximation of reality.

A surrogative inference is *sound* if it is valid and its conclusion is *true* of the target. However, a surrogative inference can be valid even if it is not sound (i.e., an inference is valid irrespectively of the truth of its conclusion) (Contessa, 2007, p.51).

Interpretation in the mind of the beholder

It is not sufficient to select a model on the basis that it simply resembles the target system, nor is it sufficient that the model fulfills a *surrogative reasoning condition*, implying that reasoning carried out with the model can be applied to the target as well. By this logic, a model may be considered a suitable representation of the target system only in the epistemic context. Depending on circumstances, the model produced in this research may be used to estimate values of variables, to examine conditions and factors that determine outcomes under various scenarios, or more fundamentally to experiment in order to learn about a phenomenon.

If a model is to serve its purpose as a *means of reasoning,* its design should take account of the eventual users.

> "A vehicle is an *epistemic representation* of a certain target for a certain user if and only if the user is able to perform valid (though not necessarily sound) surrogative inferences from the vehicle to the target." (Contessa, 2007, p. 53)

This implies that the object offered by the model should match the abilities of intended users. The object and style with which the *representation* is portrayed should be sufficiently familiar to the user that, taking account of her own skills and domains of proficiency, she can use the model to make sense of the target. A representation that is described, for example, with mathematical symbols may not necessarily be interpretable by an expert in political science whose preferred mode of expression is as narrative. So in addition to selecting a style that suitably describes the structures of the representation, it should also suit the interpretative abilities and preferences of intended users.

Gilbert and Ahrweiler (2009) provide an epistemological analysis that extends both the foundations and the interpretation of simulation and model results. They point to two extremes on an epistemic continuum – the *nomothetic*, rules based view that looks at the social world with hypotheses, "seeking generality", and the *ideographic* that seeks "to understand and explain a special case, the history of an individual formation" (p. 22). This distinction is relevant to healthcare policy studies, where trends and history are used to estimate explanatory variables on the one hand, and theory is used on the other to generate future projections. The authors recognize that, in practice, models are located along the continuum, and advise that this positioning be declared and incorporated in the analysis of boundary conditions.

Styles and objects suggest Interpretation

Ultimately a model's validity, as an instrument for planning, is in the eye of the beholder. It is the user of the model who accepts or rejects the model as a reasonable representation of the real world with which she is primarily concerned. The user must be aware of the interpretation of reality that has been used in the steps of selection and analysis of the input data, and in the theories that have been applied in estimating outputs.

3.2.5 Essential model concepts

Scientific model template

The accounts in model theory lead to four requirements to be satisfied in constructing a systems model of healthcare that is explanatory:

1. The model should include object-representation pairs, where the representation component has properties that exemplify salient features, and the characteristic properties of the object object components can be interpreted to describe those exemplification properties of the representation component.

2. The exemplification properties are chosen to map to properties imputed in the target, by ensuring correspondence between elements, relationships and functions in both the model and the target.

3. To support explanation as an epistemic purpose, the properties of the representation in the model should include counterfactual dependencies. These dependencies may be expressed as mechanisms.

4. Ultimately, the purpose of a model is realized when it can be interpreted by its eventual users, which is determined by the *style* of the object in the model by which the representation is interpreted.

Figure 3.8 adapts the account of representation proposed in Frigg and Nguyen (2017a) and subsequently depicted in Frigg and Nguyen (2018). It shows that a model represents its target as scientific by virtue of four relationships linking four constructs. The account is named for its four essential relationships.

- As a basic specification of the relationship, the model, by fiat, *Denotes* its target.

- Within the model, a representation includes certain properties that it *Exemplifies* as relevant.

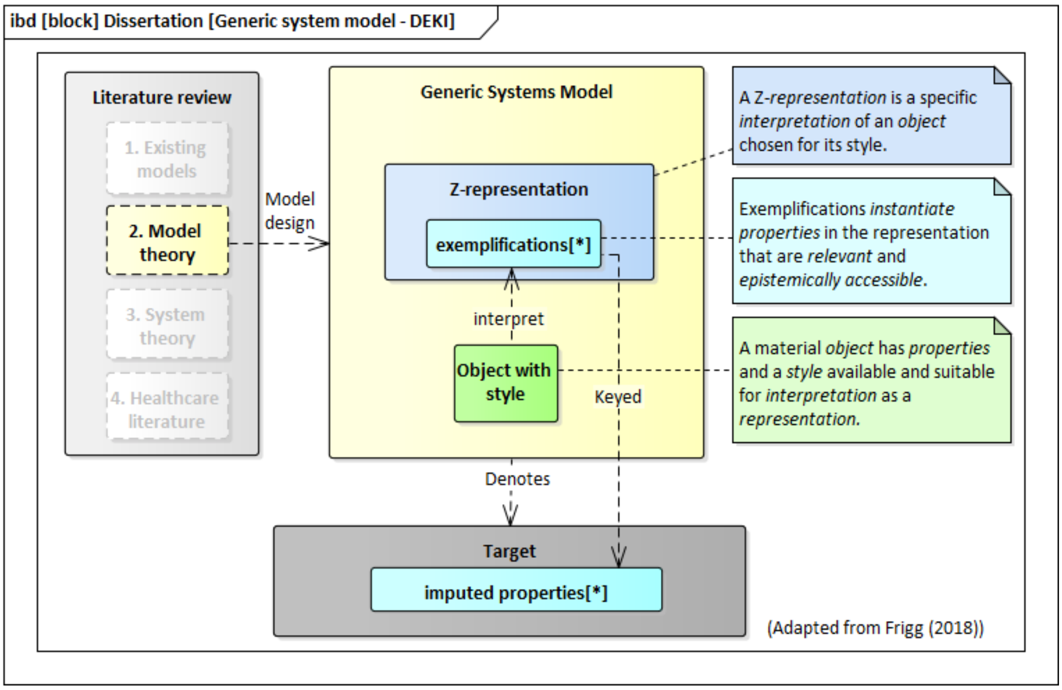


Figure 3.8: The DEKI account captures essential relationships of scientific representation (Author's own).

- These highlighted properties map with *Keys* to another set of properties
- The properties are *Imputed* to the target.

Finally, and of particular relevance in a model of healthcare, the model includes an *object* component whose style supports interpreted by users to describe the *representation*.

This account summarizes the essential structures of a scientific model, and forms a basis on which the research methodology was designed.

Explanatory models

Summarizing Bokulich (2017), a scientific model (as specified above in the DEKI account) serves an explanatory purpose when it is enhanced with these features::

1. the representation exposes *mechanisms* (i.e., combinations of entities and activities that produce change),
2. the mechanisms are *causal* (i.e., include counterfactual dependencies),
3. the extent is specified to which those mechanisms may be applied to the model's target.

These essential concepts guide the design of the methodology and of the eventual systems model of healthcare presented in Part II of this dissertation.

3.3 System theory literature

The word *system* is commonly but sometimes ambiguously applied to healthcare, yet the construct is central to successful and comprehensive innovation. System theory uses concepts and methods that reduce that ambiguity and support description and analysis of phenomena that are perceived and described as systems. With origins in the middle of the twentieth century, the science has evolved as a corpus of knowledge with which to analyze and describe structures and behaviours in many diverse field. From its early days, a taxonomy has helped minimize ambiguity in discourse. More recently, a special systems language has emerged that supports that discourse with specificity and structure.

3.3.1 Method of review of systems theory

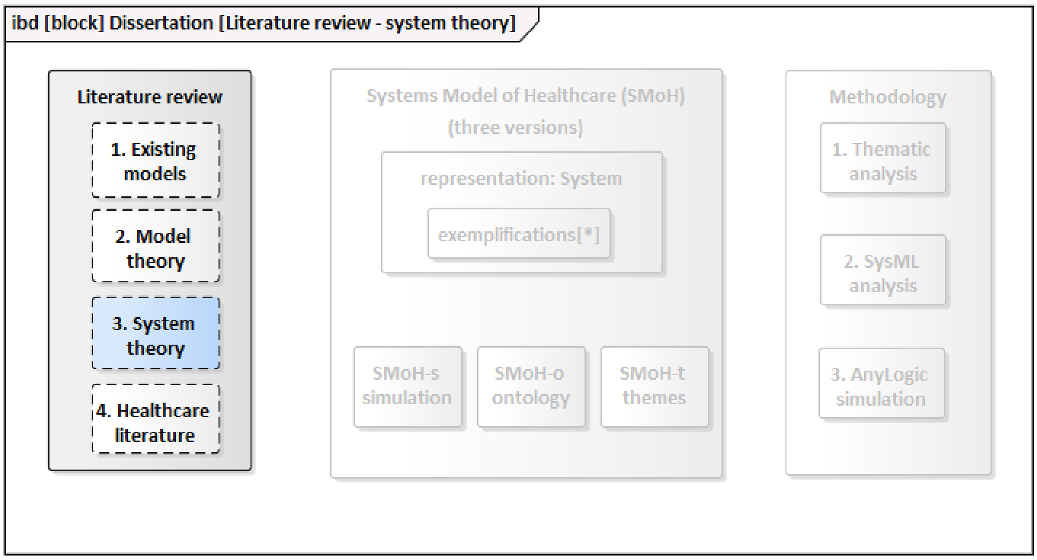


Figure 3.9: Specification of a systems model of healthcare is based on the literature of systems theory (Author's own).

The model proposed here requires that healthcare be represented as a system because that conveys wholeness - not only that there are many parts to healthcare, but that together they produce relevant outcomes - and because it conveys not only a sense of ongoing endogenous change, but of change that might be caused exogenously. After all, the main motivation for examining healthcare is to discover ways of improving it successfully, so that those ways can be realized. Those constructs are described and explained in the literature.

Review of the literature on systems theory is not simple. The word *system* occurs in the vocabularies of several scientific domains. Physicists, mathematicians, sociologists, and biologists, for example, use the term diversely. Healthcare systems may refer either to administrative or physiological constructs, and systems in information technology may point to hardware, software or global networks. However, within this diversity of definition, there is a distinction of usage that narrows the search and supports the purpose of this review. In this research, the goal is to expose the *semantics* of systems – what it means for something to be and to behave as a system.

The literature reviewed in this dissertation was selected (and continues to be) using a three phase process. The first phase began with a broad search on Google scholar, using keywords *systems* and *theory* and excluding certain specific scientific domains in the titles – *biology, chemistry, IT*. The resulting searches were limited to references cited at frequencies in excess of 50 times, or to articles published within the past 5 years. Articles that survived this filtering were gathered in a local reference manager for further examination.

A secondary review within the reference manager – reading the abstracts in greater detail, and scanning the text for salient findings – assigned appropriate keyword tags to distinguish domains and essential constructs. The reference manager includes an internal search and filtering function that complemented the manual keyword assignment. The third phase of the review examined the text of the articles tagged as relating to the theory of systems.

3.3.2 A brief history of systems thinking

General Systems Theory

General Systems Theory emerged in the mid-twentieth century as an abstraction from diverse fields such physics, chemistry and sociology of what appeared as recurring structures and methods that were used to explain interrelationships. It arose from a search for the origins of "formally identical or isomorphic laws in completely different fields" (von Bertalanffy, 1950, p. 136). It was proposed as a new scientific doctrine of 'wholeness' (*ibid.*, p. 142) in which a system is defined as interacting elements whose relationships can be characterized by sets of simultaneous linear and differential equations of first and higher order. These concepts allow analysis of phenomena independently of the scientific fields in which they were observed. Boulding (1956) extends these concepts by proposing a hierarchy of frameworks in which systems could be described, presaging the later concepts of self similarity and of fractal structures.

Dynamic systems

The dynamic aspects of systems were elaborated by Forrester and his team at MIT (Forrester, 1958). He initially introduced system dynamics in the context of operational flows for industry. As with the general systems theory the applications have broadened to include systems in many domains, including policymaking. System Dynamics adapts the differential calculus of difference equations that enabled description and specification in terms of stocks and flows, and introduced the concept of causal loops to capture nonlinear behaviours.

The concepts and principles have also gained popularity as qualitative concepts for use in developing management strategies. Senge, a colleague of Forrester's in these early developments, popularized this approach in *The Fifth Discipline* (Senge, 1990). This work stressed the qualitative aspects of dynamic systems, where the concepts of feedback and stability are applied qualitatively to the development of strategy and tactics. It contributed to widespread use of the term *system thinking*, a term has attracted its own *umbra* of ambiguity. It is variously applied to system dynamics itself (Atun and Menabde, 2008), to participatory methods associated with action research (Checkland, 2000) and to the more fundamental domain of system theory (Harary and Batell, 1981). For clarity, this dissertation refers to *system thinking* in its broad sense and not to systems dynamics which is a sub-domain.

Complex systems

Expansion of research into theories of complexity and complex adaptive systems are associated with the establishment of the Santa Fe Institute in 1984 (Waldrop *et al.*, 1992), where interdisciplinary and multidisciplinary teams – physicists, biologists, mathematicians, chemists and economists – examine the implications across several scientific domains for these behaviours, as envisaged by one of its founders:

> "The Santa Fe Institute is devoted to the study of complex systems, including their relation to the simple laws that underlie them, but emphasizing the behavior of the complex systems themselves." (Gell-Mann, 1992, p. 177)

Many of these laws and behaviours (e.g., emergence, unpredictability, sensitivity to initial conditions) have come to typify complexity as observed in healthcare (Fennell and Adams, 2011; McDaniel and Driebe, 2001; Paley and Eva, 2011, for example), although few of these have pursued in healthcare the stricter analytical and mathematical approaches developed at the institute.

3.3.3 System essentials

Despite its ubiquity in use, broadly accepted definitions of the term *system* are difficult to find. This research uses the following definition adopted by The

International Council on Systems Engineering (INCOSE):

> "A *system* is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected". (Rechtin, 2000, quoted at https://www.incose.org)

Describing healthcare as a *system* conveys meanings that activities, participants and outcomes together describe a phenomenon and place that phenomenon in the larger context of society. It is used in a collective sense to describe such attributes as total costs and expenditures, the services provided by physicians and institutions, and the various ways in which personal needs are accommodated and in which provided services are compensated. Although on occasion the word may be used with hints of irony, suggesting that what is observed in healthcare is less purposeful fragmented than it should be, *system* is used here in a descriptive rather than a normative sense.

Wholeness

Wholeness is one of the essential concepts in systems theory. It conveys the sense that although the framework within which it exists is diverse, there is a commonality among the elements that allows them to be considered collectively as a single entity. It was this sense of wholeness that drew the attention of von Bertalanffy (1950) when he initially proposed his general systems theory. As a biologist, the abstractions he used to examine and explain the phenomena in his field of research appeared quite similar to the constructions used in other fields such as physics and economics. The notion of a single entity assembled from multiple parts was not new. However, his observation was that some single entities appear to have attributes and properties that can be explained only by the attributes and properties of that entity's constituent elements collectively. In this sense, a system is more than a collection of elements with attributes, methods or purposes in common. From the perspective of general systems, the system itself has attributes, methods or purposes that are attributable both to its constituent members and to their essential relationships.

Relationships

The other essential concept in systems theory is that the *relationships* among its elements are central to the nature of a system. In his later exposition of general systems theory, von Bertalanffy (1972) emphasizes the significance of the relationships, showing that by expressing them mathematically and combining these expressions as simultaneous equations, behaviour of some systems can be explained and understood. Regardless of how they are expressed however the relationships among the elements of the system are essential in determining the character of that system.

3.3.4 System dynamics

The core mechanism in system dynamics is the accumulation and depletion in the value of a parameter (a stock) under the influence of time varying quantities of that parameter (flows). By this definition, the quantities are aggregates; they represent sets and accumulations of objects. Forrester (1958) also introduced the use causal loop diagrams as a technique for visualizing and understanding the mutual relationships among these parameters, and in particular distinguishing stable and unstable behaviours.

Stocks and flows

The construct was introduced by Forrester as a fresh approach to industrial operations, particularly to the logistics of manufacturing and supply chain management. He later expands on the strategic applications (Forrester, 1992), explaining how feedback relationships can result in nonlinear behaviour.

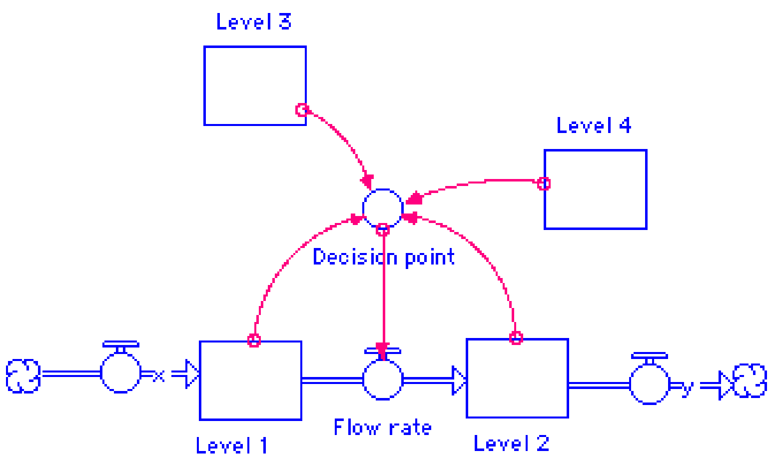


Figure 3.10: Example of a system dynamics decision model, adapted from Forrester (1992).

System dynamics extends general systems theory by adding the concept of flows and feedback (Figure 3.10). General systems theory includes mathematical relationships in several forms, including integrals and differentials. The systems dynamics approach formalizes this concept by recognizing that the values of some variables increase or decrease over time at a rate that may itself change over time. The variable that is increasing or decreasing is known as a stock, while the rate variable is known as a flow. Mathematically, the relationship between the variable that is changing, the stock, and the variable that determines the rate at which it is changing, the flow, is expressed as a first-order differential equation or as an integral relationship when the direction is inverted.

As a final note on system dynamics, the approach typically involves aggregate measures. Flows depict changes in quantity over time, and stocks depict the accumulation of those quantities. Although it is possible in computer-based applications to subdivide aggregate quantities into smaller cohorts including single elements, this is an extreme use of the capabilities, and depicting variables as types of statistical values is the norm.

Causal loop diagrams

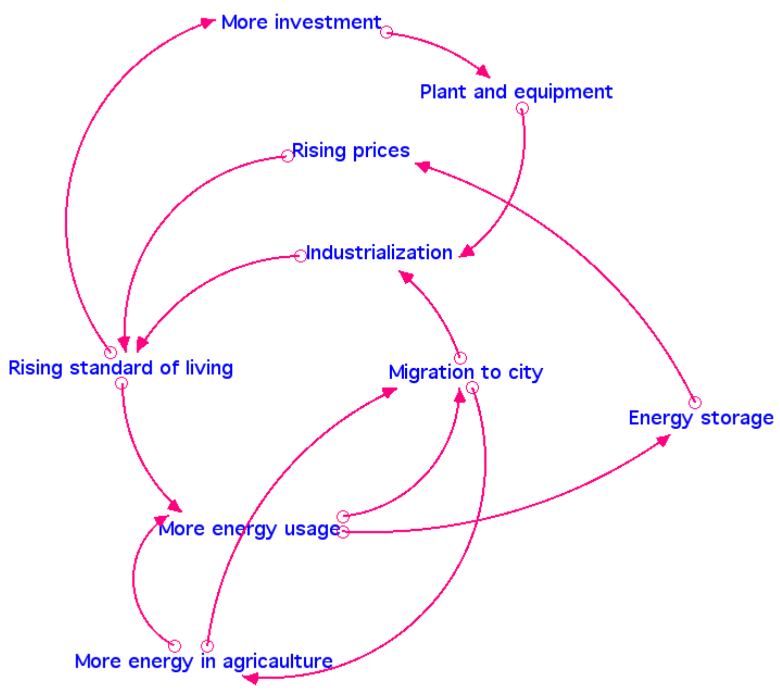


Figure 3.11: Example of a causal loop supporting decision model, adapted from Forrester(1992).

System dynamics also includes a graphical tool (Figure 3.11) with which to analyze the stability of systems of interest. The causal loop diagram identifies connections among variables, whether they be flows or stocks, paying particular attention to the direction of change of one variable relative to the direction of change of the variable downstream.

When feedback is introduced, variables may be connected in a closed loop. A variable that changes its downstream variable in the same direction contributes a positive change around the loop, while another connection that changes the downstream variable in the opposite direction contributes a negative change around the loop. The cumulative effect of positive and negative changes around the closed-loop indicates qualitatively the stability of the system at least in respect to the relationships among the variables around the given loop.

As an analytical and design tool, system dynamics methods are implemented in software, using computational methods that manage the differential and integrative functions, providing mathematical solutions for the variables and systems under assessment (Forrester, 1992).

3.3.5 Complexity

Complex systems examine systems at the level of individual objects. From the beginning, systems theories have recognized systems as individual entities with properties and behaviors, but the application of the theories treated the properties as aggregates. Complexity on the other hand addresses the behaviours of systems in which the diversity of the individual elements is retained. This exposes patterns that are may not be explained by the individual behaviours of system elements.

Although the study of systems is concerned with understanding the nature of relationships among elements, in most instances where intervention and change are the ultimate goals, the understanding extends to examining "why" relationships produce the responses that they do; why changes of state because other changes of state, why events cause other events.

This attention to simple rules in complex situations is particularly relevant to the analytical method in this research, in which the diversity that is characteristic of healthcare systems may be harnessed by applying simple rules and recognizing similarities among elements (Axelrod and Cohen, 1999).

Complex systems science was initially applied in the area of economics where the behaviour of economic systems is considered by some to be better explained at that level of granularity (Arthur, 2015; Farmer and Foley, 2009; Farmer and Geanakoplos, 2009). A review of the mechanisms that contributed to the financial crisis of 2008 included scrutiny of the underlying theories used in planning the economies at national levels (Chari, 2010), where theories are based primarily on aggregate values and on representative agents relying on mainstream systems theory. Fagiolo and Roventini (2016) argue that complex systems theory is more appropriate than the theory supporting conventional general equilibrium models in predicting the outcomes and in forming economic policy.

Authors in several disciplines note alignment of phenomena in healthcare with familiar behaviours such as emergence and unpredictability, complexity and complex adaptive systems (Fennell and Adams, 2011; Paina and Peters, 2012; Paley, 2007, 2010; Paley and Eva, 2011; Plsek, 2003; Resnicow and Page, 2008; Rouse, 2008). Again, few incorporate systems or mathematical thinking in their analyses.

3.3.6 Describing systems

Discussions of systems are approached from three perspectives. The first (i) *systems* perspective exposes the essential structures of a system; the second (ii) addresses *behaviours* that describe how changes occur. These include continuous *activities* and discrete changes in *states*.The third (iii) approaches the drivers of behaviours as they relate to the *goals* and *purposes* of the system. Some phenomena are observed only in the intersection of these perspectives; *complexity* encompasses concepts such as self-organization, adaptation and extreme sensitivity to initial conditions. And with the abundance of overlapping concepts and points of view, there is a need for a uniform and consistent way of thinking and discussing systems.

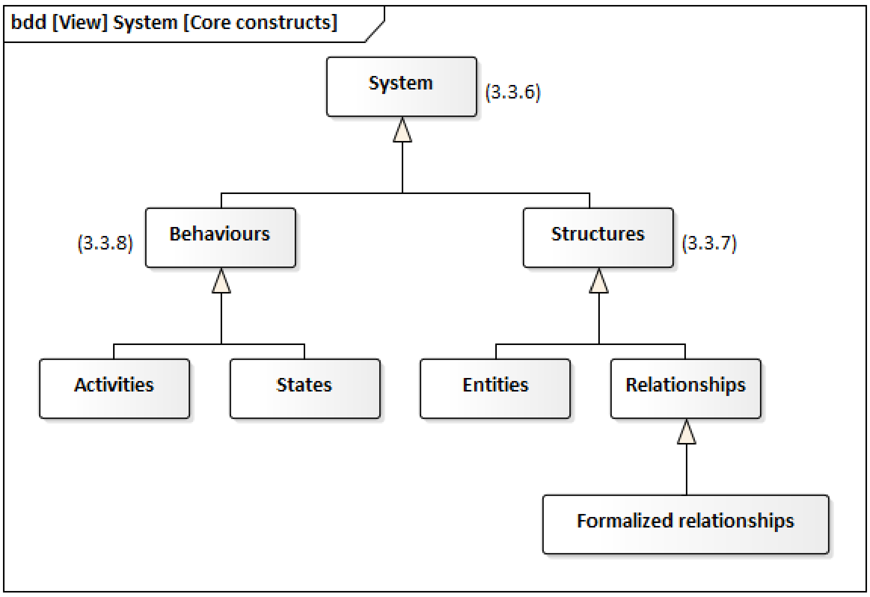


Figure 3.12: Systems are defined by their structures and behaviours (Author's own).

This section uses a frame as a taxonomy derived from the work of Russell

Ackoff (1971), a prominent contributor to systems theory. It was suggested at a time when the emerging science of systems was accompanied by a proliferation of novel terms and concepts. He averts what he describes as growing confusion and promotes a more organized use of text, context and theories. The taxonomy is sufficiently minimal to support many commonly held usages in the literature. It provides a more tractable framework within which to articulate the model requirements in this research, and to assess its results, findings and conclusions.

Figure 3.12 shows the main constructs, adapted from Ackoff (1971), with which systems are examined and described. The following sections of the dissertation define first the structural and then the behavioural branches of this figure.

3.3.7 Structures in systems

The structure of a system is specified by its parts, by features of those parts, and by the boundary that encloses those parts, distinguishing the system from everything else.

- A *system* is a set of interrelated elements.
- The *environment of a system* is a set of elements and their relevant properties whose elements are not part of the system, but change in any of which can produce a change in the state of the system.
- Every system can be conceptualized as *part of another* and larger system.
- The *state* of a system at a moment of time is the set of relevant properties which that system has at that time.
- The state of a system's *environment* at a moment of time is the set of its relevant properties at that time. The state of an element or a subset of elements in a system or its environment may be similarly defined.

Systems are recursive: they often contain other systems. At a minimum, a set of elements that are connected to one another and whose behaviour is attributable to those connections is described as a system. The term element is minimally defined, and may refer to another system. In this way, any system may be a system of systems. In the abstract, this conceptual nesting can continue indefinitely, but in practical circumstances the nature of the phenomenon to which systems concepts are applied will determine the point at which further internal specification of an element is not warranted. Reflecting thinking in the early days of general systems theory development, Boulding

(1956) identifies the various levels at which the theory would have scientific use.

3.3.8 Behaviours in systems

Behaviour is the second major construct of systems. It addresses a system's *state*, the collective value of its properties, and how those values change over time. These changes in state are of particular relevance when the produce changes in the state of other systems.

- An *event* is a change in the state of a system (or external to it) that results in a change of state in another system.
- A *dynamic* system is one to which events occur, and whose state changes over time.
- A system *reacts* to an event by changing its own state internally.
- A system may optionally *respond* to an event by initiating another event. Reaction and response are not equivalent.
- A *behaviour* is an event (i.e., a system change) that initiates other events. Behaviours therefore include reactions, and responses.

A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements or parts can include people, hardware, software, facilities, policies and documents; that is all things required to produce system level results.

The results include systems-level qualities, properties, characteristics, functions, behaviours and /or performance. The value added by the system as a whole, beyond that contributed by the parts, is primarily created by the relationships among the parts; that is, how they are interconnected.

3.3.9 Goals and choice in systems

Purpose adds to the relevance of change. As a construct, it brings in the possibility of several states that can result from change, that some of those states have greater value (however defined) than others, and that there is a capacity to select from among the changes that produce them.

- A *goal* is a state of a system, where the system has a range of responses available, and continues to exercise those responses until that goal state has been produced.

- A *purpose* is a sequence of behaviours that have a goal-producing function.
- *Purposeful* systems are those that have the capacity to realize goals in more than one way
- An *organization* is a purposeful system.
- A *choice* is a preferential selection of a response.
- An *adaptation* is the exercise of choice in response to an event, with the added goal of efficiency, which is making a choice that realizes the same goal but with use of fewer resources.

3.3.10 Causality and counterfactuals

Some of the most interesting relationships and systems are the ones that produce intentional change, whether through external forces or through deliberate interventions. The field of economics has long sought to understand how change can be detected in data, not just not just as correlation but as causation.

This search for causality has been a constant overlay in the theories and methods of statistical analysis. Granger (1988) reviews some of the prominent approaches that use prior history as a basis for predicting future values. Rubin's method (Rubin, 1974) approximates the approaches of randomized experimental methods by isolating the effects of selected independent variables on individual dependent variables. Heckman (2005) leans towards structural equation models to identify intermediate factors that may account for antecedent effects where preceded effects are known. Lechner (2010) summarizes empirical and experimental, effects, structural equations and counterfactuals.

Pearl (1995, 2009a, 2010) reaches back to Haavelmo (1943) as the basis for a *causal calculus*. This approach extends structural equation models and stresses the importance of counterfactuals: causality is determined on the basis of outcomes that have been observed when they are distinguished from other outcomes that would have occurred *only if other* conditions prevailed.

3.3.11 SysML: a language to describe systems

The systems constructs described in the preceding sections are captured more precisely in SysML (System Modelling Language). This language is introduced in parallel with the discussion of the systems theories. The standard was developed as a general purpose language for systems engineering applications (SysML.org, 2015). It is an extension of UML (Unified Modelling

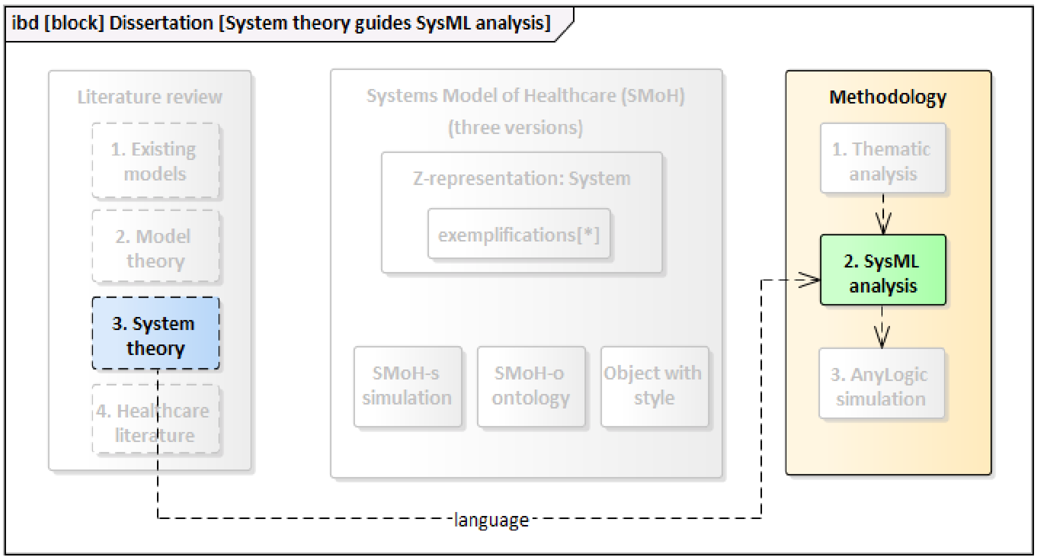


Figure 3.13: The constructs, taxonomy and language of systems forms a basis for the SysML analysis method in the methodology chapter (chapter 4) (Author's own).

Language) which was developed to support structured approaches to complex programming in information technology (IT) projects and uses a number of structural and behavioural constructs to specify the properties, methods and interactions of software components. These elements are extended in SysML to include a broader range of structural and behavioural aspects of projects in a wide rage of disciplines. They are presented in detail in Friedenthal *et al.* (2012) and in Delligatti (2013). Use of SysML is described in detail in the methodology (chapter 4) and depicted graphically in Figure 3.13.

3.4 Healthcare literature

Knowledge essential to constructing a systems model of healthcare is available in abundance in the academic literature. This corpus of information enjoys the benefits of peer review in assuring reliability and defensibility of the ideas presented. It is also rich in detail, describing a wide range of concepts as patterns, theories, constructs, variables and propositions (Suddaby, 2010). Researchers and practitioners document their observations of various areas of interest.

This fourth dimension of the literature review identifies and summarizes essential observational and explanatory information in published documents selected as an outcome of a search and screening process. More specifically, it prepares a data set from which emerge patterns of theories and constructs as essential mechanisms that can help explain how healthcare works as a system and that can be analyzed as empirical data later in the implementation of the methodology. Essential concepts include actors such as people and providers,

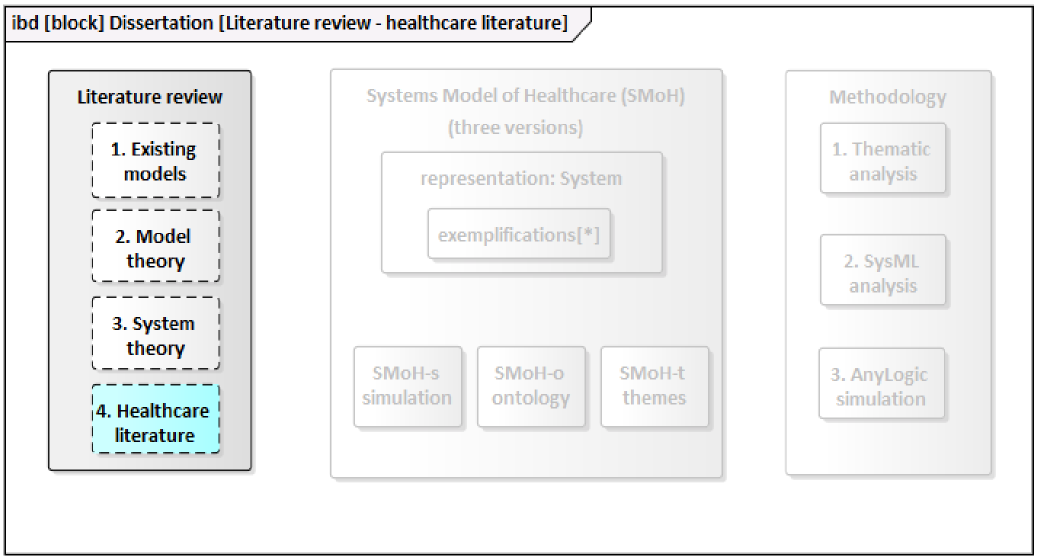


Figure 3.14: Constructs on which to base the model are found in the literature of health policy and health economics (Author's own).

abstractions such as health, illness and treatment, and activities involved in the provision and funding of services.

3.4.1 Method of review of healthcare literature

This review of the healthcare literature was designed to provide knowledge of healthcare systems as observed, analyzed and described by acknowledged experts in the domain of healthcare systems. The review was guided by two principles. On the one hand, the goal was to gather as many representations of healthcare concepts as possible within the limited resources of the researcher, bearing in mind that a minimum volume of concepts would be required in order to demonstrate the validity of the modelling approach. At the same time, the review was intended as an exemplar of a method for continuously augmenting and refining a knowledge base from which future representations can be constructed – a goal consistent with the open-ended nature of the underlying research question.

Methods of review of the literature of healthcare evolved over the course of the research. Initial searches used the keywords *healthcare* and *system* in combination with other keywords *policy, economics, comparative* and *reform*. As the searches continued, recurring references to seminal articles were followed and included in the review. The process took on many of the features of a snowball search. The criteria for selection included frequency of citation and recency of publication. Most searches were conducted initially through Google Scholar and refined through preliminary review of abstracts and references, availing not only of the features of online search engines but also of the tagging and intelligent search capabilities of a computer based desktop reference manager.

The reviewed publications covered a wide range of topics. This section loosely groups the findings that address individual health and illness, provision of care and financing arraignments.

The domain of this review, in an important sense, is not the concepts of healthcare themselves, although they are essential components of the representation to rebuild. Rather it is a review of *representations* of concepts, and in particular of those representations as conceived and expressed by authors whose reputations as experts have been affirmed by the peer review process. In many instances the content and reporting of their works are oriented to their observations and theoretical or practical contributions. The output of this review is therefore a data set of texts that is suitable for analysis to discover essential constructs of real world healthcare systems that can be consolidated and incorporated in a model as a representation of those constructs.

The selected data set also includes a series of reports collectively titled "Health Systems in Transition" (European Observatory on Health Systems and Policies, 2018), published by the World Health Organization. Each describes in detail the evolution of the healthcare systems in a particular country. The reports are prepared by one or more authors with particular knowledge of and expertise in the history and current state of the subject healthcare system. An underlying template (Rechel *et al.*, 2010) promotes consistency in reporting, addressing economic and demographic background, prevailing structures for provision and financing, and a chronology of past and intended reforms. Each draws extensively on published research similar to and at times including the material discussed in this review of the literature. They also draw on documentation and data sources both in domestic statistical repositories and those held in transnational databases such as the OECD iLibrary (OECD, 2018, for example) and the EuroStat databases (Commission, 2017).

3.4.2 Concepts of health, illness and healthcare

The review first address the concepts of health and illness; these are central to the real world and to the model. Healthcare is a social system; it is concerned with people and with health as a particular property of interest. An understanding of illness is therefore also essential. Measurement of health and of illness can be problematic in the real world, but the underlying concepts can still be described and represented.

Defining health and healthcare

Establishing a meaning for *health* and *healthcare* is the reference point for this broad ranging inquiry into healthcare systems. The World Health Organization (WHO) defines health as

> "... a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 1946)

Although this definition falls short of defining the completeness of the specified areas of well-being, it is helpful in that it places disease and infirmity in the larger context of well-being. This concept of *well-being* is adopted here as a benchmark of health against which deviations – illnesses – are observed and represented.

In a seminal document published at the turn of the millennium as a global report on the state and future of health worldwide, the WHO "... defines a health system to include all the activities whose primary purpose is to promote[3], restore or maintain health." (WHO, 2000, p.5). The inclusion of *all activities* and the declaration of *purpose* are adopted here as foundational specifications that guide the answers to the design and the theoretic questions set out earlier.

Defining illness

Accepting that health is a state of complete well-being, four related concepts – disease, illness, sickness and need – describe deviations from that complete state of health.

Boyd (2000, p.9) describes *disease* as

> "... a pathological process, most often physical as in throat infection, or cancer of the bronchus, sometimes undetermined in origin, as in schizophrenia. The quality which identifies disease is some deviation from a biological norm".

Illness, on the other hand, is

> "... a feeling, an experience of unhealth which is entirely personal, interior to the person of the patient. Often it accompanies disease, but the disease may be undeclared, as in the early stages of cancer or tuberculosis or diabetes."

[3] This definition is marginally broader than is necessary for the research at hand, since the domain of interest is with those activities intended to restore or maintain health. However, the inclusion of health promotion and disease prevention can be conveniently included as externalities to some of the component elements within the overall system.

Sickness is

> "the external and public mode of unhealth. Sickness is a social role, a status, a negotiated position in the world, a bargain struck between the person henceforward called 'sick', and a society which is prepared to recognise and sustain him."

A fourth description arises when an individual determines that the deviation however described exceeds an individuals's ability to manage. In describing behaviours associated with the use of healthcare services, Aday and Andersen (1974, p.209) describe *need* as

> "...refer[ing] to illness level, which is the most immediate cause of health service use. The need for care may be either that perceived by the individual or that evaluated by the delivery system."

The choice to access healthcare services is influenced by a number of additional factors which her colleague Andersen (1995) associate with attributes in the community that predispose to and enable utilization of healthcare services. The distinctions among these representations are relevant in representing the roles and properties of individuals as participants in a healthcare system.

Of the four designations in the previous section, illness as a personally experienced phenomenon is a property to be highlighted. It is one of a number of factors, on the one hand, that contributes to a choice in accessing care or treatment. On the other hand, it is a measure with which healthcare services in general can be represented.

It is not a stationary measure; it has a beginning with onset, and one or more endpoints with recovery or death. The intervening values of the measure follow a trajectory. This concept is referenced by Pinaire *et al.* (2017) in the context of nursing care but it is applicable in the broader context of patient experience. Illness is therefore highlighted as a time-dependent attribute in representing the dynamics of healthcare.

Illness is used here in the generic sense; it is an abstraction that represents a wide variety of clinical conditions and diseases. Each one presents with clinical measures that follow unique trajectories. Moran *et al.* (2011) for example addresses the clinical aspects of stroke as a circulatory disorder in terms of times for treatment and for recovery. Teasell *et al.* (2009) note the time for rehabilitation not only in terms of its duration but also the impact of delay in commencing that treatment. The impact of illness is a function that modifies well-being over time.

The burden of illness study, (Joyce *et al.*, 2005) for example, examines and reports the incidence of over 250 illnesses worldwide, categorized on the bass of age and gender. It provides an indication of progress, especially among developing countries, in tackling the illnesses in comparison to standards established in more developed countries.

Understanding healthcare

Drawing on more general theories of market forces in Evans (1997), Evans (2005, p. 283) suggests that to understand how healthcare systems work one should examine

- who pays for care (and how much)?
- who gets care (what kind, when and from whom)?
- who gets paid (how much, for doing what)?

Logics proposed by Tuohy (1999a,b, 2012) extend these constructs, contributing further explanation of the distinct evolutionary trajectories of healthcare systems in the US, the UK and Canada. The logics are based, on the one hand, on the roles played by professionals, regulators, and industry managers. Each, subject to different influences, operates with various types of information, implementing change on different timescales. On the other hand, changes tend to occur during "windows of opportunity"; changes in healthcare over previous decades can be explained in terms of the relative positions of the various actors while those windows have been opened.

Determinants of health

Representation of healthcare services also includes *access* as a highlighted property. Considerations with the progress of illness with or without treatment, but factors that influence the availability of treatment are equally relevant to the overall functioning of the system. Many factors contribute to that availability, Mackenbach *et al.* (2008) for example observe that correlations between educational level and occupational class on the one hand and health outcome as observed in average life expectancy and avoidable death.

Anderson and Bartkus (1984) propose a behavioural model to explain that a choice to access care results from the combined influences of policy, delivery, utilization, satisfaction and general population characteristics. A later revision of the theory (Andersen, 1995) applies the theory more explicitly to the pathways among those influences that progressively determine a decision to access care.

Quality of care

Representing the patient outcomes of healthcare services as exemplifications is necessary in a systems model. Although strategies and policies are formulated against a backdrop of patient well-being and population health, the specifics of patient outcome are difficult to observe, and arguably have been under-represented in planning and accounting for system performance. In "Crossing the quality chasm: a new health system for the 21st century", the Institute of Medicine (2001) draws attention to an under-reported level of adverse events observed at the turn of the millennium, including an alarming level of avoidable deaths. The authors question the general effectiveness and safety of healthcare delivery, including coordination among providers. Publication led to the formation of the Institute for Healthcare Improvement (IHI) as an organization advocating for change in healthcare systems strictly from a professional delivery perspective but with a focus on patient safety, satisfaction and successful outcome. The initiatives of this organization focus largely on learning but they also incorporate the development of indicators relevant to the quality of patient experience. The institute advocates adoption of a "Triple Aim of Healthcare" – improving care experience, population health and overall affordability (Berwick *et al.*, 2008).

In the absence of measures of quality with a human focus, a limited number of indicators represent as proxies the effectiveness of healthcare systems. Hospital readmission is one such measure, where evidence suggests that under usual conditions a readmission to hospital is interpreted as a system failure (Jencks *et al.*, 2009; Stefan *et al.*, 2012).

While access to healthcare may be limited in absolute terms, it may also be restricted in relative terms. People in need of care and with the ability and capacity to access that care may not receive it right away. Waiting for treatment is a phenomenon observed in many healthcare systems. Siciliani *et al.* (2013) survey a number of countries in which waiting times have been reported, examining the factors contributing in the policies that have been implemented to relieve the problem. Waiting for services, particularly those that are not required in emergency or urgent circumstances, is normally associated with capacity limitations. These in turn are linked to constraints placed on systems experiencing funding pressures. The strategies employed typically divert patients to other jurisdictions or sectors of the system with available capacity, and often at an economic cost to the domestic system.

3.4.3 Healthcare system variables of interest

Developing a representation includes identifying certain properties that are highlighted in order that they may be keyed to corresponding properties in the target system – the *exemplifications*, the *E* in the DEKI account. In the language of systems, these properties together constitute the *state* of the healthcare system. Smith and Papanicolas (2013) review several frameworks that are used to assess the performance of our healthcare system, focusing on the properties that relate to the patient as recipients and as purchasers of care. They suggest a general framework Table 3.3 in which the specific indicators can be viewed.

Table 3.3: Framework of healthcare system performance indicators

Areas of interest	Examples
Population health	Life expectancy, mortality, morbidity, population risk factors
Health outcomes	Performance in different sectors of care, system processes and outcomes
Equity	Distribution of health status and access by social groups
Financial protection	Out-of-pocket expenses, catastrophic expenditures, fairness of financing
Satisfaction, responsiveness and experience	Patient satisfaction, promptness of attention
Efficiency	Value for money, waste of resources, disease costs

A scorecard developed originally for the evaluation of healthcare systems domestically is used in the report of the Commonwealth Fund (2008) that ranks healthcare systems across a few countries (increasing from six in 2007 (Davis *et al.*, 2007c) to eleven in 2017 (Schneider *et al.*, 2017)). Despite the original focus on hospitals and systems within the individual states and counties, the structure of the indicators is generally regarded as adequately broad yet sufficiently parsimonious to serve as a common framework within which to compare systems internationally.

The indicators are grouped under five major headings. *Healthy lives* captures survival measures including infant mortality, mortality amenable to healthcare among the population in general, and certain measures of illness such as those leading to schooling time lost the younger children and limitations to activities of daily living among the older population. An overall *quality* indicator captures certain procedural structures and processes of care delivery, such as visit scheduling and co-ordination, that are considered of a well-functioning system. This indicator does not address issues related to the quality of outcomes from the patient perspective. *Access* assesses several dimensions of healthcare insurance as a proxy for the degree to which individuals can receive care when needed. *Efficiency* combines measures of administrative overhead, variations in treatment practices, and inappropriate use of medical services, such as accessing emergency care when primary care would be more appropriate, or delivering care in an inpatient setting where and ambulatory settings would be available and appropriate. Finally *equity* assesses disparities among sectors of the population the ability of individuals to access necessary care. Evaluation under this heading is distinct from the earlier assessment of overall access in that it focuses on the social aspects that qualify insurance coverage, whether public or commercial.

The indicators are adapted to the international context and updated periodically using surveys administered to participating international partners. Overall rankings are estimated using appropriate weightings although the relative importance of the individual indicators cannot be assessed from these reports

Given the difficulty in acquiring concurrent data on the personal experience of illness, average measures of survival are used as proxies for the overall effectiveness of healthcare systems (Lubitz *et al.*, 2003). Average life expectancy is an estimated measure of remaining years of life for a representative person at a given age. It is based on average mortality rates in the previous period and is therefore updated regularly as other determinants (such as public health measures and improving rates of employment and education) modify the overall health of the population. For this reason, it is only a proximate representation of health status in the population.

Other indicators of survival relate the provision of healthcare services with health outcomes in a more direct way. Disability adjusted life years (DALY) estimate the difference between average life expectancy for the population and remaining years of life typically associated with an illness or group of illnesses. Variants of these adjusted indicators include projected years of life lost (PYLL) and quality adjusted life years (QALY). These indicators track more closely to the performance of the healthcare system in terms of accessibility and effectiveness but each is considered deficient in some way (Chen *et al.*, 2015; Sassi, 2006). Life expectancy and disability adjusted life years are reported for most countries (Murray *et al.*, 2013; Salomon *et al.*, 2013) as part of the Global Burden of Disease study previously cited.

Grossman (1972) offers the Human Capital model as a different representation of health and illness. Adapting the macroeconomic concept of consumer utility, he specifies *wellness* as an additional durable stock that diminishes with age but may increase with investment. As a concept, it is relevant to the optimization processes inherent in macroeconomic models, but health status measured as "illness free days" is a useful representation of the individual experience in the maintenance and restoration of health. In the research world of healthcare systems, measures of wellness and health status as experienced by individuals are notoriously inaccessible; self-reported health status is known to be subject to unintended bias. Since the intention of the model is to *represent* a property considered important in the target system, inaccessibility of that property in the target context does not preclude its inclusion in the model. Inclusion of *wellness* in the model is therefore useful as a representation of health.

As a service to its member countries and to the public at large, the OECD collects and maintains an extensive database of economic and social indicators (OECD, 2017, 2018). The underlying data are collected from the national agencies in member countries and are therefore subject to some variation in definitions and in scope. Recent efforts at standardization have improved the quality of data.

The underlying structure of the extracted data sets indicates not only the richness of information that is available, but the range of indicators that are considered relevant in comparing healthcare systems across countries, and in assessing their performance. The health theme used in this study in particular includes a broader range of tables including health status, health expenditure and financing utilization, and social protection. The ranking report (Schneider *et al.*, 2017) and the International Profiles of Healthcare Systems (Mossialos *et al.*, 2017) published by The Commonwealth Fund draw heavily on these databases.

3.4.4 Provision of care

GATEKEEPING/ACCESS

Reibling (2010) examines mechanisms that explain access to healthcare across different countries. These include gatekeeping, cost sharing and supply of provider services (physicians in particular). Gatekeeping is the role played in certain jurisdictions by primary care physicians in managing access to other sectors of the healthcare system as one factor in managing utilization and cost. The study addresses theses mechanisms with a view to clustering countries, but not to their impact on other indicators such as cost or outcome.

PEER ASSOCIATIONS

Broadly based mechanisms in healthcare rely on coalitions and collaborations. Borow *et al.* (2013) examine the significance of the levels of cooperation between professional associations on the one hand and governments and provider organizations on the other, noting that cooperation tends to be higher in European countries than in the US or Canada. From a broader social and economic viewpoint Granovetter (1978) advances a model of group behaviour that explains coordinated behaviours of individuals in groups based on diverse thresholds in the choices individuals make that can lead to changes in uniform behaviour. The mechanism[4] is applicable to the peer-to-peer relationships among clinical professionals referenced by Tuohy (1999a), for example.

PRACTICE VARIATION

Variation in clinical practice among physicians has been and continues to be an issue in explaining the relationships between the delivery of adequate care and the costs associated with that delivery (Appleby *et al.*, 2011; Brownlee *et al.*, 2017; McPherson, 1989).

COORDINATION

Delivery of effective care requires coordination among clinical professionals; patterns of care have evolved with specialization of functions among and within the professions. The report by Institute of Medicine (2001) notes gaps in the quality of care delivered in U.S. Hospitals due to ineffective communication and hand-off processes. Benham-Hutchins and Effken (2010) note lapses in the maintaining and communicating of salient patient information in the course of a patient's pathway through care.

3.4.5 Governance of healthcare

Governance include several mechanisms that determine or at least influence the provision of healthcare and the associated expenditures. There are three relevant aspects to its representation in a model.

The first is the functional role, wherever located, in allocating resources (Guindo *et al.*, 2012). It may occur at a state level in assigning portions of national revenues, in a provider organization in selecting which production streams will receive portions of funding and revenue, or in a commercial form such as a pharmaceutical company or an insurance provider in setting strategic goals and aligning them with financial plans.

[4]Miller and Page (2004) describe the mechanism in terms of standing ovations, at public concert events for example.

The second representation relates to the participation of the state at times as a provider, frequently as a funder but most often as a regulator. This role has gradually changed in many healthcare systems in recent decades, as the state reduces its intervention in all three aspects of healthcare (Jakubowski and Saltman, 2013; Saltman and Duran, 2015) .

The third aspect of governance is related to the second in that the locus of allocation and intervention may move from the national level to regional and local levels, as has been reported widely in the Swedish system. (Anell *et al.*, 2012, for example).

3.4.6 Funding and social protection

While the goal of healthcare systems clearly focuses on maintaining and restoring health in the population, the functioning of a healthcare system is inextricably associated with the financing and allocation of resources; this warrants essential representation in a model.

There are three main concepts in financing healthcare systems: flow of payments, distribution of risk and allocation mechanisms including market competition. Kutzin (2008) reviews these in some detail as guidance to decisions taken at various levels within the system, both locally within organizations and nationally at a policy level.

Cost and Efficiency

The first concept is simply that of the flow of payments. It is represented by the normal functioning of exchanges where goods (in this case professional treatments) are exchanged for payments.

The resources provided as inputs to providers are converted into outputs, however poorly realized (Evans *et al.*, 2010). Improving the system through policies will entail, at those points, the productivity of the providers of care. There are other determinants of outcome also, still within the boundaries of healthcare proper, but productivity tends to be at the centre if many policy changes.

A number of studies have compared countries on the basis of their efficiency. Many of these have their origins in the study((Evans *et al.*, 2001, forexample) associated with the publication of the World Health Report (WHO, 2000) that compared the efficiencies of the healthcare systems in 191 countries. The study ranks performance of each country using an index of efficiency based on health expenditures and levels of education. The design, based on statistical frontier analysis of panel data (Battese and Coelli, 1995), adapted and extended by others (Gravelle *et al.*, 2003; Greene, 2004; Hernández de Cos and Moral-Benito, 2014; Wranik, 2012).

Payment types

Table 3.4: Eight types of payment

Unit of payment	Common term	Examples
Per time period	Budget and salary	Salaried physicians, nurses
Per beneficiary	Capitation	Managed care
Per recipient	Contact capitation	Physician speciality services
Per episode	Case rates, payment per stay	Diagnosis related groups (DRG)
Per day	Per diem and per visit	Nursing facilities, long term care
Per service	Fee-for-service	Physician visits, hospital outpatient, clinics
Per currency cost	Cost reimbursement	State owned facilities
Per currently charge	Percent of charges	any provider

Source: Adapted from Quinn (2015)

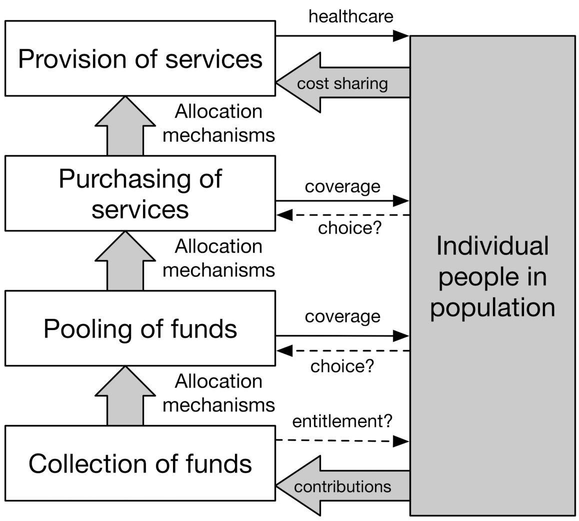


Figure 3.15: Fund flows and allocations to providers, adapted from (Kutzin, 2008))

The payments that flow to providers are calculated on several bases (Quinn, 2015), listed in Table 3.4 and through several chanels (Paris *et al.*, 2010). The overall effect of this sharing of risk and of payment is reflected in the many channels through which funds are gathered, allocated and eventually directed to the providers of care, and is represented in Figure 3.15.

Insurance as protection

The second concept under *funding and social protection* is that of risk sharing. In economic terms, illness has negative utility, and people who encounter illness will expend income to reverse that if possible. It is a random process with potentially significant consequences for personal and for financial well-being. For this reason, all healthcare systems offer or maintain a form of health insurance, either implicitly by providing service in kind, or explicitly either as government mandated or supported schemes, or through independent or private insurers. The overall diversity among healthcare systems in specific countries is largely reflected in the different approaches to health insurance.

Certain distortions occur however when services are prescribed and priced (Arrow, 1963). These are attributable to asymmetries of information. One relates to the physician's access to *privileged information* – the value to the purchaser of the services she offers. The other asymmetry relates to the behaviours of seekers and sellers of health insurance - the opposing effects of adverse selection and of moral hazard. One party, the principal, agrees to pay some portion of the expenses incurred by the other party, the agent. Depending on the share, and on the levels of (ill)health, the choices made by the principal and the agent can influence the level of expenditure - and by extension, the access to care as a portion of overall demand (Geoffard, 2012).

Markets and competition

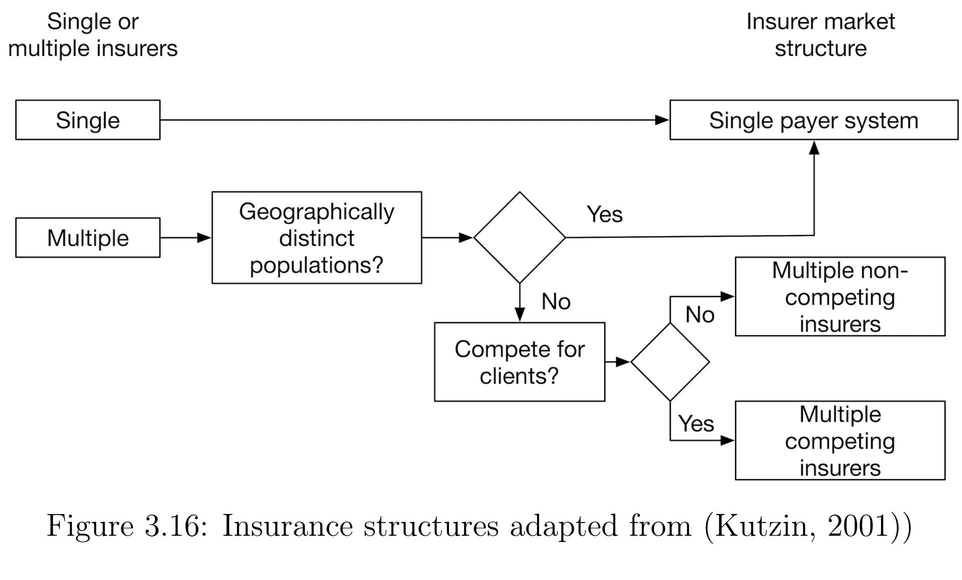


Figure 3.16: Insurance structures adapted from (Kutzin, 2001))

Competition is associated with improvements in efficiency. Figure 3.16 shows how opportunities for competition arise in some configurations of a health insurance regime. In the Netherlands and in Switzerland, these conditions exist, although their effectiveness in managing healthcare costs at a national level is debated (Okma and Crivelli, 2013).

Managed competition has been attempted in a number of countries (van de Ven *et al.*, 2013; Victoor *et al.*, 2012). The strategy's logic rests on the belief that competition promotes efficiency in production resulting in lower costs or improved quality (possibly both). Commercial insurers offer insurance plans to individuals in the Netherlands and in Switzerland (van Ginneken *et al.*, 2013) while in England the NHS implemented an internal market among to provide services to commissioning agencies (Oliver, 2012b).

3.4.7 Patterns in the evolution of healthcare systems

Reforms have been attempted in individual countries. Oliver *et al.* (2005) reflect on the difficulty in comparing the evolution of healthcare systems across countries in part because there appears to be little uniformity in goals or in indicators of outcomes. A few country examples illustrate trends, both common and diverse.

In the evolution of the NHS in England, for instance, trends in health expenditures matched shifting policy reforms associated with the changes in political leadership through the Thatcher and Blair administrations. During both eras, the policy focus had been on improving efficiency and on containing costs although each relied on different mechanisms, the former on competitive markets, and the latter on budgetary control Oliver (2005). In Spain, on the other hand, a policy change devolved governance from a national to a regional level increases inefficiencies were observed, but discrepancies in input variables measuring access did not appear to change Lopez-Casasnovas *et al.* (2005).

Meanwhile, the healthcare system in Ireland has evolved over a two decade period (Wiley, 2005) during which the country experienced unusually high economic growth. There has been a growing use of private insurance, and a reduction in the numbers eligible to receive services without charge. Comparing the admission rates to private and to public hospital beds shows a notable increase in waiting times and reliance on a special purchasing scheme that transfers patient flow from the public to the private system, while in the Netherlands, the distinct consultative and collaborative approach characteristic of its society – the Polder model – has influenced the evolution of the healthcare system over the past decades (Okma and de Roo, 2009) . During this time, the various corporate, private and government actors have managed to implement significant policy and structural changes that were achieved mainly through coalitions and accommodation, but also through episodes of trial and error. And finally, the evolution of the healthcare system in Denmark (Pedersen *et al.*, 2005) has been gradual over the past decades. It has coincided with gradual shifts of responsibility and of governance from the national level to the regional level in counties, with consolidating facilities, and with introducing budgetary controls that apply regionally or nationally.

3.4.8 Levels of change

Tuohy (1999a) compared the forces and constraints that have marked the extent of changes in the healthcare systems in England, Canada and the U.S. In Tuohy (2018), she focuses in the underlying parameters of those changes, noting that they can be distinguished both by pace of change and by degree. In the field of national financial policy, Hall (1993) suggests that changes can be distinguished by levels at which policy must operate, reflecting both the locus and the extent of deviation from established trajectories. From a hard sciences, systems perspective these levels align well with the mathematical concepts of continuity and differentiability; both representations are indicative of the disruption entailed at each level.Although commenting on financial policies at a national level, the constructs are applicable in the healthcare domain as well.

In Hall's terminology, the first level of change refers to an action taken to close a gap between an observed value of a parameter and the intended value set as a target in adhering to a chosen policy. This aligns with normal feedback in physical systems, and with the final *action* step in the *Plan, Do, Check Act* cycle advocated in the change management literature (Deming, 1986), and with the routine in-cycle adjustments to operations in meeting annual production and budgetary targets.

The second level refers to a revision of the target to better realize the overall goals of the chosen policy and strategy. In management terms, this is analogous to the *double-loop learning* advocated by Argyris (1982). Mathematically, it is a change in a change, the definition of a second order differential, marking a non-linearity that warrants appropriate computational treatment. Operationally, second order changes typically occur when plans (as opposed to operations) are reviewed and updated, often annually in preparation for a future period of operations.

At the third level, the strategies themselves change. This represents a substantial revision to the direction of a system. Mathematically, it corresponds to a second or higher order differential, functionally the type of discontinuity associated with phase shifts and tipping points. Socially, this level of change entails conflict, negotiation, compromise – and possibly gaming.

3.4.9 Essential patterns and theories in healthcare: a summary

This review of publications in section 3.4 reveals concepts relevant to the mechanisms of healthcare systems. Certain publications reviewed here were were

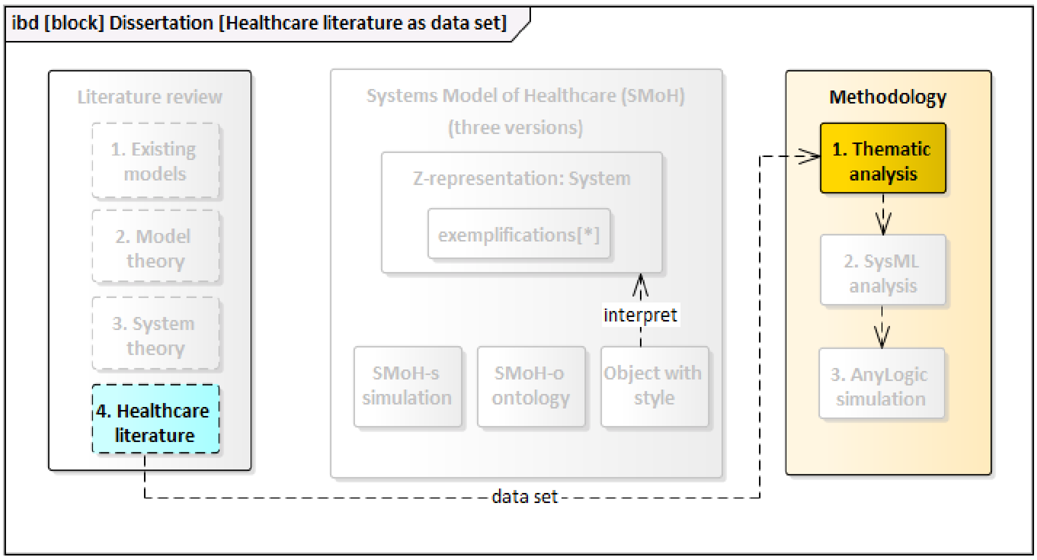


Figure 3.17: Articles selected in the review of healthcare literature serve as a data set for the thematic analysis method in chapter 4 (Author's own).

selected as sources of empirical qualitative data in the experimental design of this research; they constitute the data set in which thematic analysis reveals essential patterns of the *what, how* and *why* of healthcare as a system. This is detailed in the methodology chapter 4, as depicted in Figure 3.17, and later reported in the foundational themes version of the systems model.

3.5 Chapter summary

The chapter reviews literature relevant to the research. This both exposes gaps in knowledge and practice, and provides foundations on which to build answers to the research questions. A review of the literature on existing models reveals strengths and some shortcomings in the scope and findings both within healthcare and in wider domains. Model theory provides concepts with which to approach the problems of representing the real world artificially. Similarly, the literature on systems provides theoretical and applied constructs as building blocks and a language for use in developing a model. Finally, a range of articles and book chapters provides a corpus of qualitative data from which core structures, constructs and theories may be extracted and systematically analyzed.

Part II: A Systems Model of Healthcare in Three Versions

Chapter 4

Methodology: How to build a Systems Model of Healthcare - SMoH

The methodology answers the two research questions – the *design* question, how to build a model, and the *theoretic* question, how healthcare works as a system – using a framework to construct a model in three stages.

It adapts the structure of the DEKI account of a scientific model previously reviewed in the literature on model theory (cf. Figure 3.8 in subsection 3.2.2) and meets its purpose of providing explanations by building a model of healthcare systems in three related versions. The first version meets the surrogate reasoning condition by using thematic analysis to describe the representation component exemplifying healthcare. In the second version, a specific language refines the counterfactual dependencies in the representation, restating generic healthcare systems as a formal ontology. A computer simulation implements the refined representation in the third version of healthcare to demonstrate the model's experimental potential.

The representation, particularly as described in the first themes version, helps answer the theoretic question.

This chapter describes the methodology that was developed to answer the research questions posed in chapter 2, building on the literature foundations reviewed in chapter 3. It first places the three methods in the context of systems engineering, adapting established methods for describing systems in general. The chapter then describes how each of the three methods is applied first to extract and analyze constructs of healthcare as themes, then to restate those themes and constructs more formally as a systemic ontology, and finally to implement the specified as a simulation that exposes for examination and explanation some of the essential mechanisms of healthcare.

4.1 Answering the research questions

The methodology in this research is designed to answer the first two main research questions identified in chapter 2. One of these calls for a theoretic finding:

> *What* ***pattern*** *proposes how healthcare functions as a whole system?*

The model account that emerges in the literature on the sciences of models is adapted to meet the requirement of this question. The second question calls for an artifact:

> *What* ***model*** *can be constructed that represents healthcare as a system?*

Using the theoretic model account, the *representation* itself – the patterns of structures and elements that map to target healthcare systems in the real world – is described in three complementary *styles* that enable diverse users to interpret and infer.

The methodology is a sequence of methods each selected to meet the design requirements. The first stage analyzes the empirical content of the literature in a selected data set, establishing in the representation the essential features and mechanisms of healthcare systems using theory. This addresses the second, theoretic research question by providing a pattern that unifies known theories and constructs. The style of narratives and network diagrams used in this first stage is well suited to describing the representation of the empirical content, but the description lacks specificity necessary for robust reasoning used in logical and formal analysis. In the second stage, a graphical language suited to systems description restates the *themes* description. The version describes the core representation structurally and functionally as an ontology that can be accessed by design specialists. This description is then used as a basis for presentation of the core representation this time in the style of a computer simulation that is comfortably within the skills and cognitive abilities of diverse professional users.

SMoH is introduced as an acronym referring to the Systems Model of Healthcare as described in all its versions. For clarity, each individual version distinguished by it style is assigned suffix, e.g., SMoH-t designates the themes version.

4.1.1 Model Based Systems Engineering (MBSE)

The methodology adapts Model Based Systems Engineering (MBSE), an approach developed primarily for the design and deployment of complex technical physical systems (Ramos *et al.*, 2012). In its conventional use with systems yet to be built, it gathers the intended behaviours of the systems, with a particular focus on its intended purposes and applications. The uses and goals identify essential objects, their activities and their relationships to one another, eventually specifying them in a language suitable to representation as a system with structures and behaviours.

In the conventional application of the method, developing the model is the penultimate[1] stage. It serves both as a vehicle for testing the viability and performance of a proposed system and as a stable reference from which to deploy the actual system later either physically or as software, depending on the original requirements. In this research, the process concludes with the development of the model of healthcare in three versions.

MBSE for the model account

The first application of MBSE addresses the design and construction of the model itself, using the theory-based DEKI account as a template. It takes as guidance the requirements set out in the premises and in the questions, and establishes appropriate object-representation pairs to satisfy them.

This is an uncomplicated application of MBSE. The goals and intended purposes are prospective, interpreted as artifacts yet to be built.

MBSE for the healthcare model

The second application of MBSE addresses how that representation is constructed to realize the explanatory function. It describes synthetic elements and activities in patterns of mechanisms and dependencies that represent healthcare functions as a system. In so doing, it implicitly addresses the theoretic question.

This second application of MBSE is a modification to the conventional approach. Whereas the requirements in an engineering design are usually prospective, expressing as narratives the needs to be met and the intended purposes of the system yet to be built, the narratives of healthcare are retrospective, depicting systems as they *already exist*. Instead of analyzing and deconstructing new material, the requirements phase in building the model uses as content the structures and behaviours that have been observed by experts and expressed by them in the language of the social sciences.

4.1.2 Philosophic positions: critical realism

The critical realist perspective describes the philosophic stance of this research. The introduction established the basis for a model: that planning and maintaining healthcare as a collective process requires a shared view that includes

[1]The final step is the implementation of the modelled system.

an understanding not just of what it is, but also of how it works. This perspective is known as critical realism.

The philosophical positions of this research are revealed in several ways in Part I of this dissertation. The motivation to describe healthcare as a system takes a realist ontological position: that healthcare is a reality that exists beyond the concepts and quantities used to describe it. The aim of developing a model as a practical instrument for exploration and experimentation specifies explanation as an epistemological position. The research questions *how* to construct a model, and *how* healthcare works as a system.

This philosophical framing of the research is well described as critical realism. Critical realism addresses shortcomings in positivism and empiricism, the philosophical positions of many of the econometric studies of healthcare cited in the literature review. Those views of reality are primarily quantitative, using correlation among observations as structural descriptions of reality. Causal relationships are limited by experimental design and are difficult to validate. Causal realism takes a broader view beyond empirical observations.

Danermark *et al.* (2002) address the methodological implications of adopting a critical realist position. Effective approaches to acquiring scientific knowledge, they summarize, includes observing the structures of the domains of interest, and examining the mechanisms that operate in generating and responding to change. The philosophical stance does not limit observation to quantitative methods, and may extend to qualitative methods such as case studies and content analysis. The methodology of this research aligns with this critical realist paradigm.

4.2 Structure of the systems model

The systems model is designed as a representation of healthcare that, in each stage of the methodology, exemplifies the properties of a system. The representation is shaped with mechanisms and counterfactual dependencies that enable surrogative reasoning.

4.2.1 Requirements of an explanatory scientific model

The model is made of two components, each designed to meet the requirements of a scientific model. The first component is a *representation* component that meets the requirements of *surrogative reasoning*. This representation is populated with *mechanisms* – entities and activities producing outcomes. The mechanisms, once gathered and implemented using a separate process, are highlighted as *exemplifications* and mapped to properties of target health-

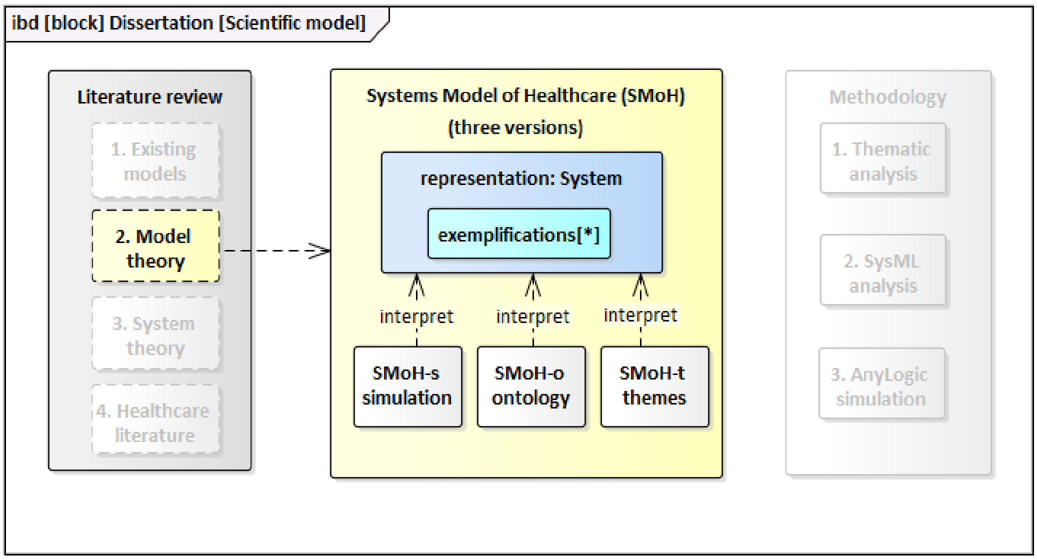


Figure 4.1: The structural design of the systems model of healthcare is based on theories of scientific models (Author's own).

care systems in the real world. To support the *epistemic* requirement of explanation, the mechanisms are structured in the representation to represent *counterfactual dependencies*. Since the representation contains diverse entities, activities and structures, the model uses a variety of objects to describe it.

The requirements of an account of the model-*representation* in this dissertation, guided by the questions in Table 3.2 in subsection 3.2.3 are satisfied in the following design choices:

1. The epistemic representation is to provide learning insights through experimentation with scenarios that vary available parameters in the model.

2. The model is to represent healthcare from a critical realist standpoint.

3. Available styles include narrative themes, ontologic specifications and simulations using one or more of discrete event, system dynamics, microsimulation and agent-based modelling.

4. The standard of accuracy for the initial implementation of the model is limited to coarse-level precision assessed heuristically, and accurate only as to general direction of change.

5. Three versions of the model are intended, making use of the three stages in construction. These are described in the remaining sections of this chapter.

The *explanatory* requirement is satisfied by ensuring that the thematic analysis identify and code themes as *mechanisms*, representing counterfactual dependencies found in the documents of the data set.

4.2.2 Three methods for creating a Systems Model of Healthcare - SMoH

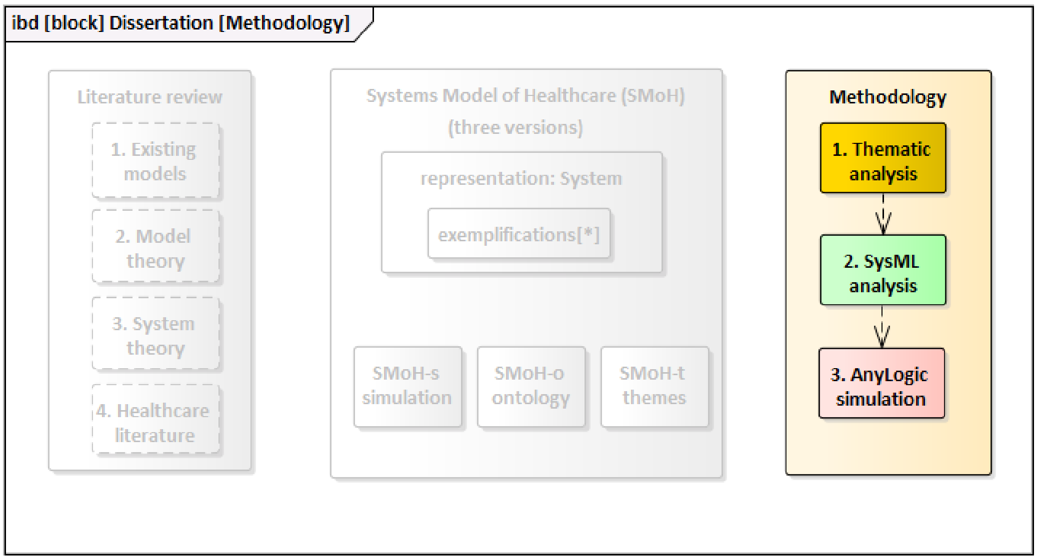


Figure 4.2: The methodology refines a model structure applying three methods in sequence (Author's own).

The chosen methodology proceeds in three stages. The first stage is one of discovery. *Thematic analysis* is used to find and extract the empirical data, the *constructs* and their *meaning* from an abundant literature on healthcare The second stage restates the narrative findings of this analysis with greater precision as a *specification*. It uses SysML, a systems language designed to capture and express them as a well structured framework. Finally, the system specification is *seen more clearly* by implementing it as a software based *simulation*.

4.3 Method 1: Thematic analysis: acquiring the theoretic content

The rationale is that the model, to meet the surrogative reasoning condition, should be built with elements, relationships and functions that correspond to elements and relationships and functions in the real world. Furthermore, to meet its explanatory purpose and extend beyond a simple description, the

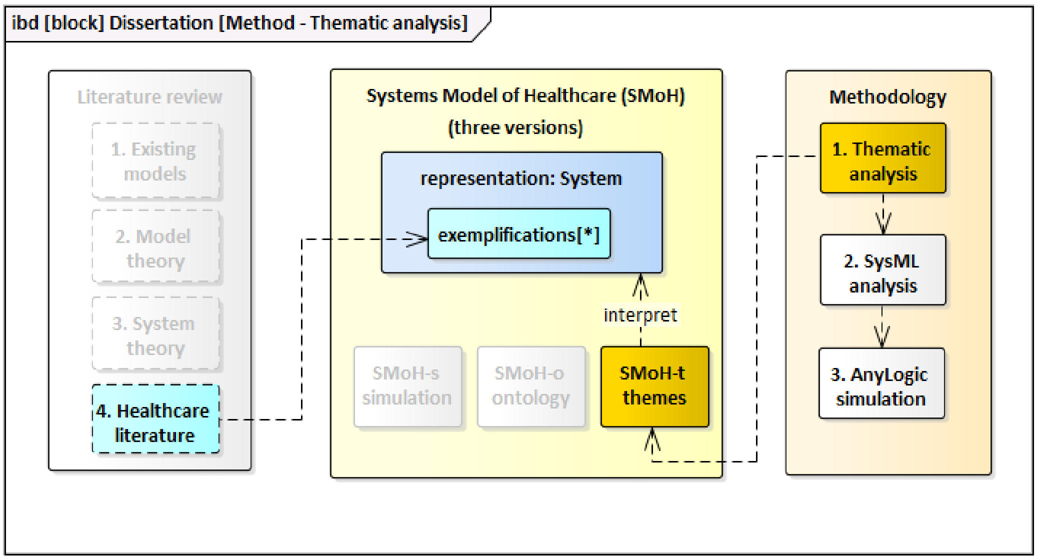


Figure 4.3: The first method, thematic analysis, encodes constructs found in the healthcare literature, describes them as themes (Author's own).

correspondence between model and target should include counterfactual dependencies.

As the review in the previous chapter demonstrates, the healthcare literature is an abundant source of knowledge of such elements, relationships, but it is diffuse, fragmented and structured inconsistently. Gathering and organizing that knowledge is an exercise in sensemaking, not from the crisis management perspective (Klein, 1999, 2004; Weick, 2009), but with a view to sorting through unordered concepts and relationships, and to discerning logically consistent patterns that can be articulated (Kreps, 2009; Weick, 1989).

In the absence of a ready-made theoretical framework, one is assembled from available fragments. The fragments are expressed as narratives or as correlations (at times causal relations) in diverse places, using diverse language to describe constructs, variables, hypotheses and propositions. Content analysis is suitable for comprehensive extraction, and the thematic variant is suitable for organizing the content coherently.

The first method constructs the *representation* at the centre of the models and describes it using the *style* of themes (Figure 4.3). Thematic analysis distills and organizes domain expertise that is widely dispersed in the literature. Based on a preliminary template, the method assembles codes that identify elements, properties and mechanisms that emerge as key mechanisms across quotations from the documents in the selected data set. Tools in the content analysis software support development of a hierarchy of codes first as basic themes, subsequently as higher level organizing themes and ultimately as a single, unifying theme. Entities and activities within these themes are further identified as mechanisms.

4.3.1 Choice of literature as a knowledge source.

In this research, the healthcare data is harvested as domain expertise in the healthcare literature, although modellers normally use knowledge provided by small groups. The literature approach is chosen for two reasons.

Some modellers rely on local problem owners for this knowledge (Lane and Husemann, 2008; Viana *et al.*, 2014, for example), on expert panels convened locally (Esensoy and Carter, 2017), regionally (Logtens *et al.*, 2012; Pruyt *et al.*, 2011) or nationally (Congressional Budget Office, 2007; Goldman *et al.*, 2004). This generic approach was rejected in favour of the literature as a source for several reasons. The scope of this model to be constructed here extends to the boundaries of a given system, ruling out local consultation only. At the other extreme, national agencies preparing large models avail of networks of expertise and of resources to assemble panels whose insights are collected usually through facilitated sessions and assembled as data upon which models are constructed. Neither the networks nor the resources are available to this researcher. Furthermore, panels convened at a particular time tend to reflect current, prevailing thinking only, and depend on the presence and mix of participants for diversity of viewpoints and time horizons. This consideration applies even to locally convened panels.

On the other hand, it can be argued that the trove of domain expertise in the literature is more broadly based conceptually, temporally and geographically. The collective time horizons are extensive, and more complex effects may be observed, at times as counterfactual instances. The peer-reviewed literature can also be accessed over and over again, supporting the model's ongoing refinement. In this respect, the approached here is transparent and less subject to *local bias*.

4.3.2 Rationale: acquire theoretical constructs of healthcare

It is a requirement that the model include essential constructs of the target system, and that it reflect a counterfactual structures. Although healthcare provision and assessment is well served by a broad range of theories and constructs, a *coherent* theory is not available. This method treats these existing theories and constructs as empirical data in which relationships and patterns are discovered using content analysis of that data.

Healthcare appears complicated. There are many elements and mechanisms to consider, and every country appears to approach its delivery uniquely. This method assumes that beneath the heterogeneity there are commonalities in structure and behaviour that can be identified as invariants in the structure, and that the observed heterogeneity can be distinguished as variations in properties of those core structures and behaviours. As a general principle, Page (2010) supports such an explanatory association between diversity and complexity. As an extension of thematic analysis, network analysis (Attride-Stirling, 2001) supports and exposes this construct.

A principal reason for building a model of healthcare is to gain an extended understanding of healthcare by observing phenomena that are not currently observable, either because they have not occurred or they are not observable. A model forms a basis of knowledge from which new knowledge can be inferred. By this reasoning, it must be assembled from and represent sound knowledge.

Qualitative texts, identified in the course of ongoing literature review, are drawn from the reviewed publications of acknowledged experts in healthcare and in the supporting engineering and policy domains. They are coded, analyzed and grouped as progressively more generalized narrative representations of healthcare systems.

The task is to extract the relevant concepts, to identify their commonalities where they exist and to relate these commonalities to one another so that together they will represent healthcare as a system. Content analysis, as a method of coding narrative concepts, is well-suited to the task of extracting information such as this. More specifically, two implementations of content analysis – template and thematic – together meet the requirement. As Boyatzis (1998) sets out, the method of thematic analysis are intended precisely for discovering and articulating the global themes that together describe and explain phenomena of interest.

4.3.3 Essentials of thematic analysis of healthcare system literature

Thematic analysis is "a method for identifying, analysing and reporting patterns (themes) within data." (Braun and Clarke, 2006, p.97). It is a form of content analysis that extracts and organizes texts to synthesize the constructs and variables as themes that represent the underlying theories as expressed by the authors of the texts.

> "A theme is a *pattern* found in…information that at minimum describes and organizes the possible observations and that at maximum interprets aspects of the phenomenon." (Boyatzis, 1998, p. 4, emphasis added)
>
> "(Another) pair of competencies involved are planning and systems thinking. They enable a person to organize his or her observations

> and identified patterns into a usable system for observation (i.e. that others can use, or that the person can use consistently at other times)".(*ibid*, p. 5)

King *et al.* (2004) and Crabtree and Miller (1999) clarify that template analysis is the preferred form of content analysis when pre-existing codes are available. The review of systems and mechanisms provides sufficient concepts to support a provisional codebook with which to begin the analysis. This template approach augments thematic analysis in meeting the second requirement that the model capture patterns of knowledge.

Attride-Stirling (2001) uses network analysis as an organizing mechanism. The method identifies intermediate themes in a progressive process of summarizing and aligning the concepts as global themes that describe the phenomena of interest from complementary and comprehensive perspectives.

The initial codes were based on a template developed *a priori*, as suggested in Fereday and Muir-Cochrane (2008). They incorporated a taxonomy suggested by Ackoff (1971) previously discussed in subsection 3.3.6, augmented with concepts included in the systems language, introduced in subsection 3.3.11.

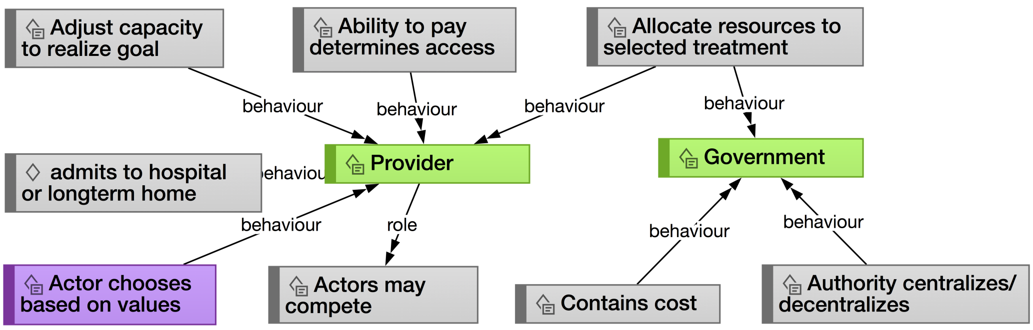


Figure 4.4: As analysis progresses, mechanisms were allocated to linked actors (Author's own).

This was extended as the analysis of documents suggested codes that were not in the original codebook. With further progress, some codes were merged to reflect common meanings, and in the interest of parsimony to capture essential concepts and avoid detail that appeared unnecessary in representing the underlying healthcare concepts. Others were extended to distinguish certain types of elements (e.g., actors as special elements in Figure 4.5). As the analysis progressed, the activities were allocated to actors (Figure 4.4) and subsequently segregated in levels that distinguished basic, organizing and global themes.

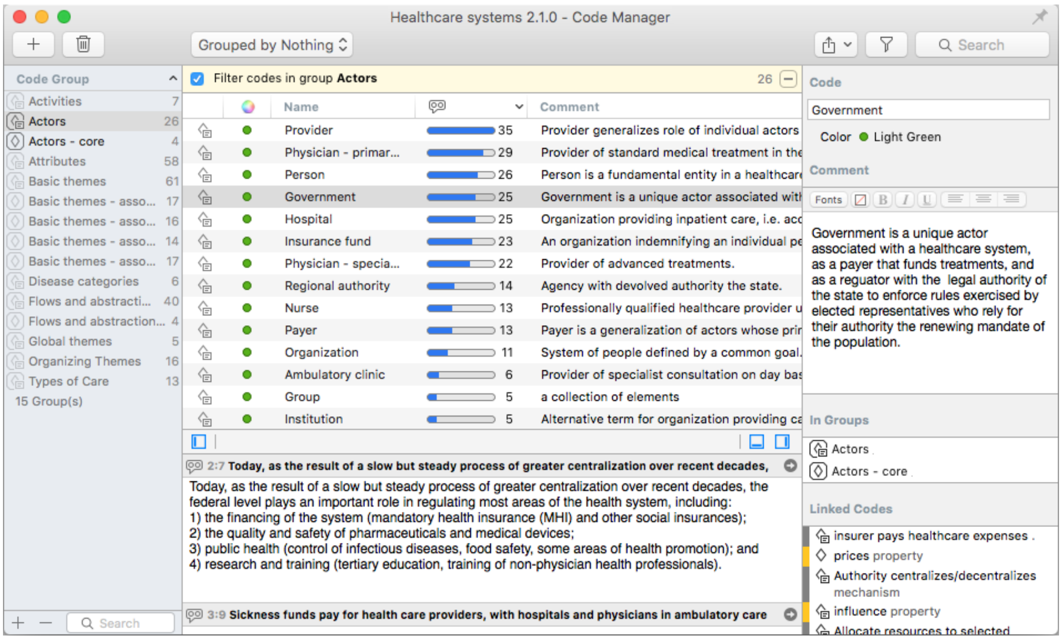


Figure 4.5: The code manager capture codes, displays statistics, comments and links, and organizes in code groups

The template for coding was based on two sources. The first was the systems taxonomy by Ackoff (1971), previously described in subsection 3.3.6. The taxonomy anticipates the overall structures of systems. The second drew on the constructs and actors identified by Evans (2005), that distinguished the individual person as a patient, the provider of treatment, and the parties to the exchange of payment. Combining the two produces the code groups identified in Table 4.1.

4.3.4 Template and code groups

The content analysis of the documents in the data sets used a preliminary template that distinguished codes representing elements, attributes and activities. This included familiar and expected elements such as *Person*, *Patient*, *Physician*, *Hospital* and *Government*, to name a few. Attributes included *health status* in various forms, *expenditure* and *access* – these concepts having previously been noted in the course of the literature review. At first only a few activities, such as *treating* and *paying*, were included pending analysis of the documents. As expected, the range of distinct elements, attributes and activities expanded as analysis progressed.

The codes evolved over the course of analyzing the quotations found in the literature. Initially, the code book was based on a core set of concepts, following the process suggested in Braun and Clarke (2006, p. 283). Evans (2005) suggested asking “Who pays for care (and how much)? Who gets care (what kind, when, from whom)? Who gets paid (how much, for doing what)?”,

Table 4.1: Code groups

Name	Comment
Actors	People and organizations as system elements
Flows and abstractions	Entities that are generated and exchanged by otherl entities through their connections. These flow entities may be persistent or transient. Flows may be physical entities themselves (e.g.
Disease categories	Diseases for which treatment may be provided.
Types of Care	Treatments that are provided as part of the bundle selected to treat a given diagnosis
Attributes	Attributes are values
Activities	Activities are the reactions and responses of entities to events. Most activities occur through relationships among entities
Basic Themes	Basic themes are the lowest level of association among codes.These themes are lexical expressions in which entities are described in terms of attributes
Organizing Themes	Organizing themes are lower level descriptions that distilled as a global theme. Each theme includes lower level basic themes that describe relationships among entities
Global themes	Global themes are the top level themes that together describe the underlying system. Each master theme includes themes.

Source: Adapted from Ackoff (1971) and Evans (2005)

which suggested codes for *Providers, Funds, Persons (as Patients), Treatment* and *Illness, Timing.*

This set of codes grew rapidly as salient attributes and relationships were found and were subsequently refined and merged as meanings were found to overlap substantially. Codes were also divided into groups to preserve the similarities and distinctions among their different types - entities, attributes and activities, for example. The groups were further extended to capture the levels of basic, coordinating and global themes at they emerged.

4.3.5 The coding process

Figure 4.6 illustrates how template analysis tames the heterogeneity of language and expression in the published literature. Ignoring for now the detail

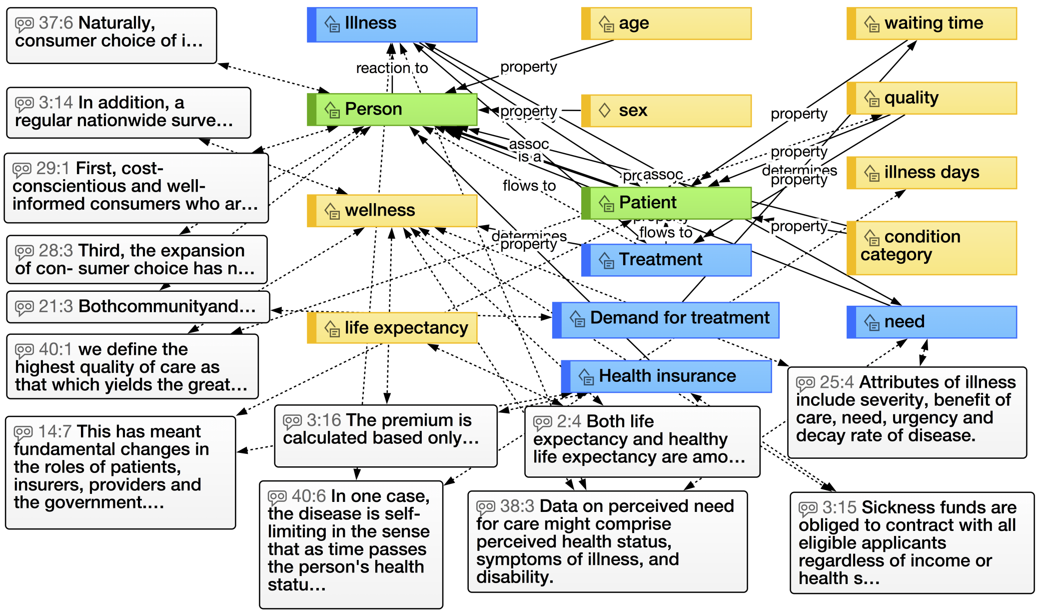


Figure 4.6: Many quotations converge to limited code types, distinguished by colour code) (Author's own).

of the individual elements in the figure, it shows how links from elements link to various quotations. The quotations, in turn, link to other elements exposing patterns of connection among the codes. In an iterative process of adding and taking away codes and quotations, and of refining the linkages among the codes themselves, patterns emerge that reveal meaning and make sense of the underlying linkages. These linkages and the codes that they connect, condense the expertise contained in the analyzed documents, and form the substance of the generic healthcare system in the following sections. The details of Figure 4.6 are elaborated in these sections.

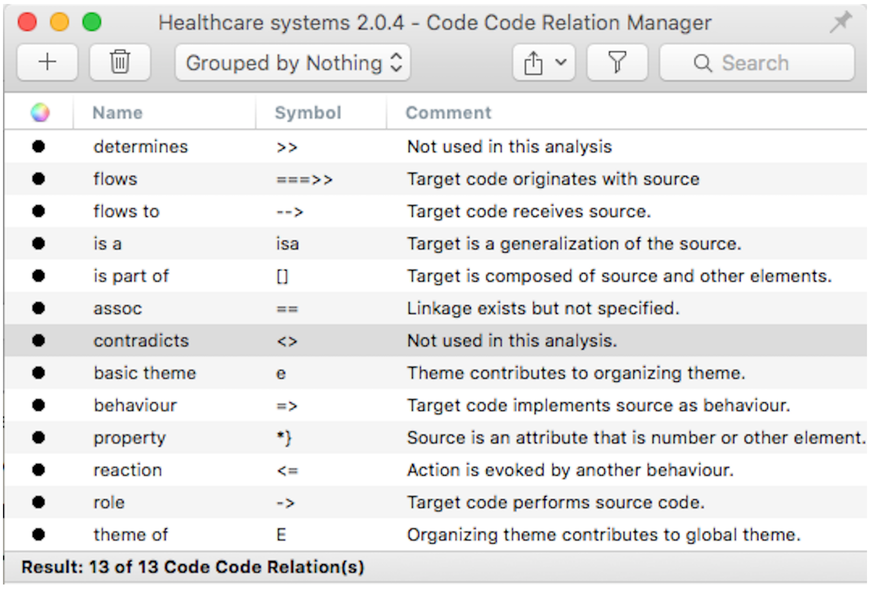
Coding of structures is a straightforward process of identifying the co-occurrence of elements and attributes in quotations (Boyatzis, 1998). Eventually a saturation point is reached at which the combination of refined and structure codes was sufficient to code new quotations. Structures and hierarchies emerge harnessing the diversity of types and features and introduced manageable structure to the elements and attributes.

This is a cyclical and iterative process that continues into and overlaps with the later thematic phase. Codes from the codebook are assigned to quotations from the selected documents, attempting where reasonable to assign multiple codes to each to support later analysis of relationships among codes. Inevitably this phase of coding reveals both gaps and overlaps in meanings and linkages, leading to refinement of the codebook. With these refinements, it is at times necessary to revisit quotations that have been previously coded to update with newly defined codes, or to consolidate those that have been collapsed into one.

As codes are added and modified, their reference meanings are recorded as comments attached to code names. In this research 86 codes were identified. The subsequent analysis process manages this extensive range by identifying commonalities among codes. Some codes are distinguished for instance as different properties associated with another common entity, while others share common structures but are distinguished by their constituent entities. Details of these analyses are described more completely in reporting the findings of the analysis in a later chapter.

4.3.6 Discovering themes

The second stage of content analysis structures the codes extracted in the template phase and examines them in more detail. The patterns of relationships that emerge are coded as themes capturing meanings shared within these patterns. Attride-Stirling (2001) suggests that intermediate themes be identified in a progressive process of summarizing the concepts and then aligning them as global themes that describe the phenomena of interest from complementary and comprehensive perspectives.



Healthcare systems 2.0.4 - Code Code Relation Manager

Grouped by Nothing

Search

Name	Symbol	Comment
determines	>>	Not used in this analysis
flows	===>>	Target code originates with source
flows to	-->	Target code receives source.
is a	isa	Target is a generalization of the source.
is part of	[]	Target is composed of source and other elements.
assoc	==	Linkage exists but not specified.
contradicts	<>	Not used in this analysis.
basic theme	e	Theme contributes to organizing theme.
behaviour	=>	Target code implements source as behaviour.
property	*}	Source is an attribute that is number or other element.
reaction	<=	Action is evoked by another behaviour.
role	->	Target code performs source code.
theme of	E	Organizing theme contributes to global theme.

Result: 13 of 13 Code Code Relation(s)

Figure 4.7: Custom relations defined in Relation Manager (Author's own).

The analysis phase identifies and captures the various ways in which codes are related. Figure 4.7 illustrates the custom set of relations among element and activity codes. Elements that generalize other elements (e.g., Provider generalizes Physician, Hospital, etc.) are associated with "is a" relationships. On the other hand, elements that are composed of other elements (e.g., persons belong to populations and to organizations) are associated with their component elements with "is instance of" relationships. Flows among elements were

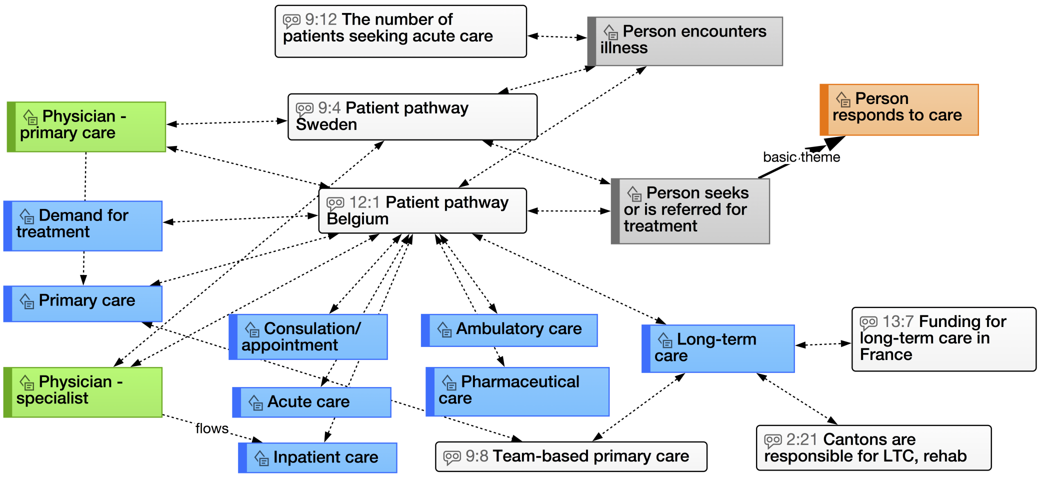


Figure 4.8: Relationships explored with Network Analysis

identified with *flows* and *flows to* relationships, intermediated with the element that flows.

As the analysis of quotations proceeds, the codes in the codebook reach a certain level of stability. When additional new quotations are examined, the existing codes are found adequate to capture the essence of the construct of interest, and it becomes less necessary to define new codes. This applies both to the code groups that identify entities and their properties, and to those that identify and describe activities.

Once this stage is reached, the first stage of assembly and thematic analysis of *basic themes* begins. As discussed previously, the representation of the target system is constructed using mechanisms, which in turn combined entity with activities. The preliminary collection of basic themes is therefore assembled by ensuring the coded activities already identify the associated development on the properties, or that those associations are clarified within the text of the basic theme (see Table 4.2).

The application used to support the analysis (ATLAS.ti) includes features to assist in exploring and coding relationships: the graphical Networks enable selection and combination of related codes. The iterative process begins with a speculative selection of codes (as, for example, in Figure 4.8), and proceeds to add and remove related elements, attributes or other types of codes until a cogent and consistent pattern emerged. The application's Code Forest feature provided a complementary approach to establishing and refining relationships among codes (Figure 4.9).

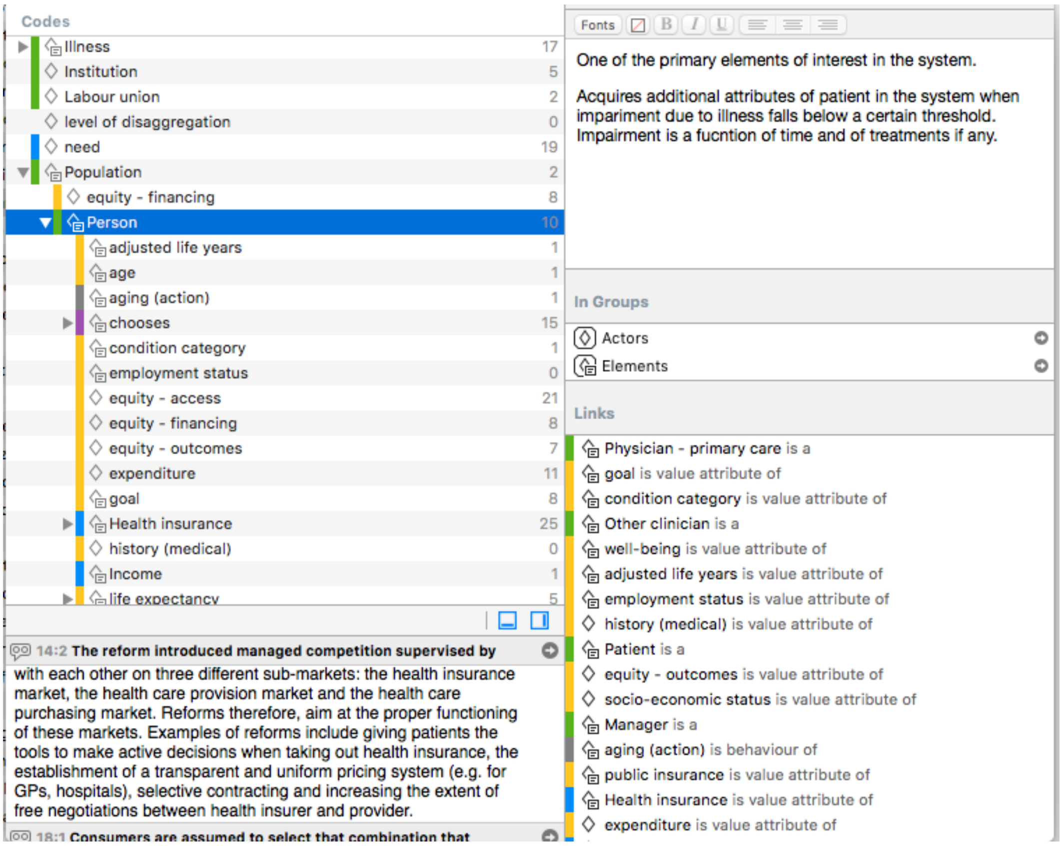


Figure 4.9: Codes forest for Person (Author's own)

4.4 Method 2: SysML analysis: specifying healthcare as an ontology

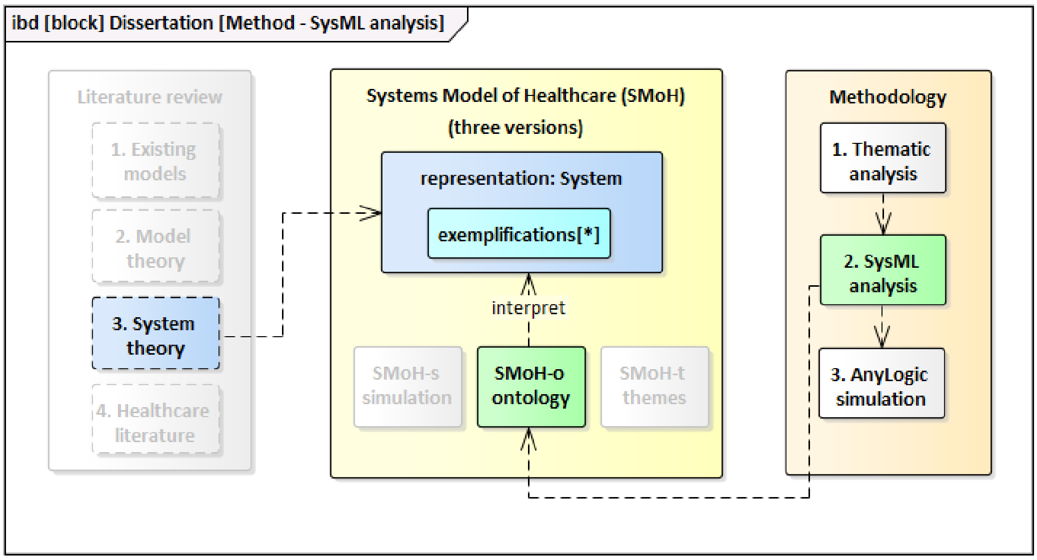


Figure 4.10: The second method translates the themes as an ontologic specification using SysML, a systems language (Author's own).

Formally, the overall specification of healthcare as a system is a means of

Table 4.2: Custom relations defined in Relation Manager

Name	Short Name	Symbol	Comment
assoc	assoc	==	
basic theme	thme	e	
behaviour	beh	=>	One of a pair of the complementary behaviour/reaction relations.The source code is a behaviour and is associated with the target code that implements the behaviour.
contradicts	A	<>	
determines	det	>>	
flows	flows	===>>	
flows to		–>	
is a	spec	isa	Specifies that target is a generalization of the source. For instance
is part of	owned	[]	Specifies the element codes that make up the target code. These correspond to a *has-a* relationship. The ownership is not necessarily unique. A part property is distinguished from a value property in the property is an instance of another element
property	prop	*}	Specifies an attribute that describes the state of the element with some variable value. A part property is distinguished from a value property in the the property is an instance of another element
reaction	react	<=	The complement of a behaviour. The source code is a behaviour code
role	role	->	Some elements that are essentially distinct may nonetheless have additional features in common. In particular
theme of	subthm	E	In thematic analysis

expressing and sharing the concept concisely and precisely – this is the essence of an ontology, as discussed in the review of the literature on system theory (section 3.3).

The ontology is constructed using SysML as the chosen ontological language (Jenkins, 2010). SysML has been specified as an extension of UML (Unified Modeling Language) the language developed to support complex programming projects. Its primary use is in supporting development of advanced engineering projects, and as such it contains many behavioural and time-dependent constructs that can capture the various concepts with which healthcare

4.4.1 SysML: a language of systems

The diversity in the literature on systems presents a challenge in that the concepts themselves are diverse and interrelated. The methods and results of the research reported later in dissertation are couched using a standard language for systems. Extending the spirit of the taxonomy, SysML is a graphical language that has been refined over the past decade (Object Management Group, 2016). In promoting clarity of specification and therefore of communication, it support the practice of Model Based Systems Engineering (Delligatti, 2013; Friedenthal *et al.*, 2012; INCOSE, 2016) in designing and documenting complex technical systems.

The formal specification of SysML states that

> *SysML is specified using a combination of UML*[2] *modelling techniques and precise natural language to balance rigour and undesirability.* (Object Management Group, 2016, p. 17)

The modelling techniques uses diagrams and graphic elements to specify the structures, behaviours and purposes of a system. The language is introduced here as a companion to the taxonomy and as an essential dimension of systems theory.

4.4.2 Structures of systems

Two fundamental constructs describe a system – that it is a set of entities, and that all those entities are linked to one another to form a single entity. SysML uses the *block* graphic element to depict a single entity, and the two constructs are shown in a pair of block diagrams.

These concepts are represented diagrammatically first in Figure 4.11 (and later in Figure 4.13). The system of interest exists in an environment that also contains other systems that are associated in various ways, and the states of individual systems are observable by other elements in the same environment. It is in a given environment that the relationships exist.

Relationships are specific. SysML for most purposes uses what is known as an internal block diagram (IBD). The relationships are simply designated with connecting lines, using the SysML symbols either hierarchically as generalizations (shown with directed arrows), or through ownership, both by composition or association (shown as closed or filled diamonds, respectively.)

[2] *Unified Modeling Language* has evolved since the early 1990's as a graphical language to support development of computer software. The evolution of SysML as an extension of that language began in the early years of the millennium. It is now in its fourth revision as SysML 1.4.

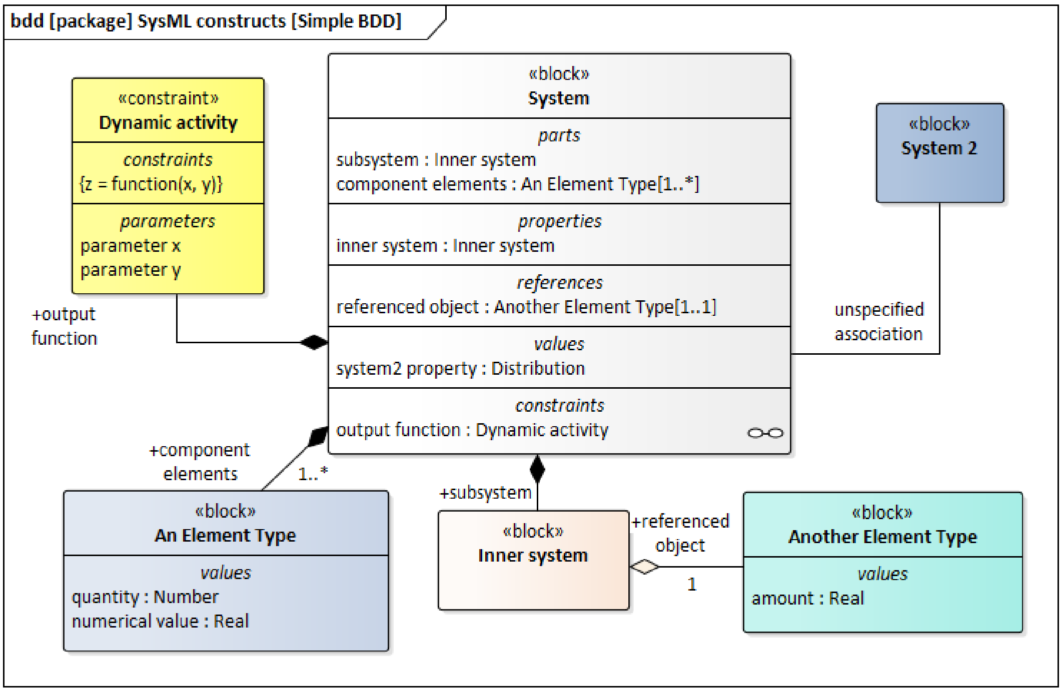


Figure 4.11: A system is a set of elements in an environment that may contain other systems (Author's own).

The elements of a system are typed as appropriate, and may be associated collectively or individually. The SysML representation distinguishes between those elements that are *owned* by a system and elements that may belong elsewhere in the larger environment where the representation is simply a *reference* (signified by an open diamond icon at the tip of the connector). This distinction is relevant in the systems model of healthcare where, for example, people and providers may participate in more than one system but not be owned by any one of them. The elements of a system may themselves be systems.

Block definition diagram (BDD)

Entities are the fundamental elements in a system. They can take any form – physical, social, abstract – and are characterized as a minimum by one or more properties. Graphically, an entity is represented as a *block*, within which the properties are listed. Properties may also take many forms. They may be numeric variables that may take various values, but they may also be logical or categorical values, or even instances of other entities that in turn are characterized by their own properties. In Figure 4.12, for example, the entity of interest is represented by a block names *Entity 1*, with four properties: weight, a numeric value expressed in kilograms, *visible*, a logical variable with available values of *true* and *false*, *phase*, a categorical variable with three available values, *solid*, *liquid* and *gaseous*, and a variable named *core*, which points to an instance of another entity of type *Entity 2*, which may have its

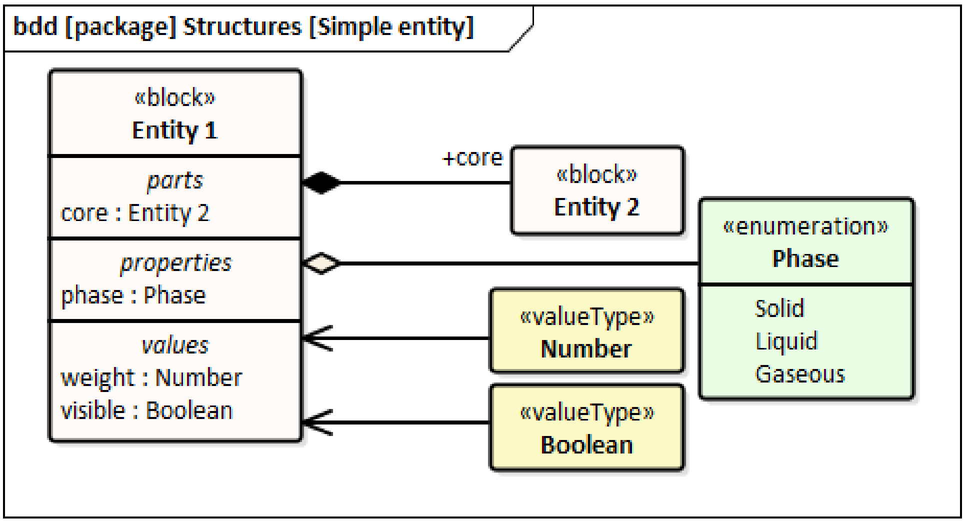


Figure 4.12: An entity is the rudimentary element in a system (Author's own).

own set of properties.

Figure 4.12 uses additional constructs of SysML to display the nature of the linkage between property types and a particular entity. These are addressed later in this subsection.

One is hierarchal, depicted by arrows at the head of the connecting link connecting. This relationship indicates the block at the head of the arrow *generalizes* some behaviours of the downstream blocks in some ways. This means that although the underlying mechanisms are fundamentally similar and specified by default in the generalized block, they are implemented in different ways in each of the specialized blocks. So, for instance, a generalized *flow* is generated in one block and influences another block. The specialized blocks – information, treatment or payment – generate their content in different ways. The same type of relationships applies to the several ways that various Providers produce and deliver treatment.

Another indicates ownership or inclusion, depicted by diamond shapes, either open or filled, at the head of connecting links. The distinction relates to inclusion or association. A filled diamond indicates that the downstream block exists only while the connected block exists. An open diamond signifies a transient association between two blocks that exist independently of each other.This linkage indicates that the downstream blocks are effectively properties of the upstream one. This structural relationship, like the hierarchical one, also captures diversity and heterogeneity across systems while at the same time retaining consistency and homogeneity

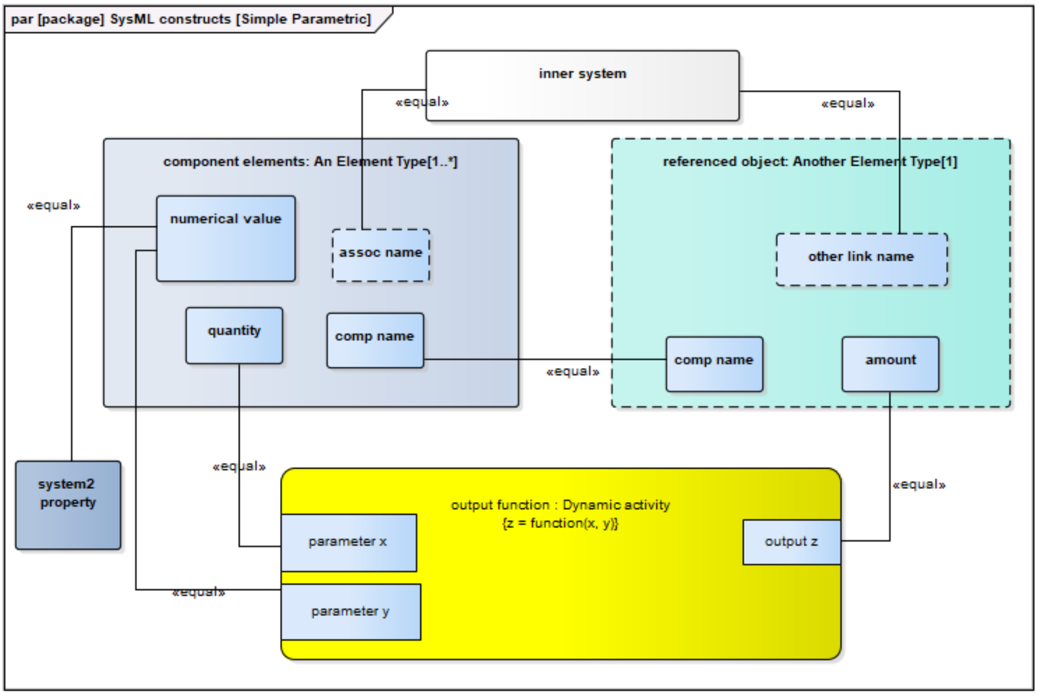


Figure 4.13: The internal block diagram (IBD) shows the functional relationships between the system's entities (Author's own).

Internal block diagram (IBD)

This diagram makes use of the extended *constraint* block feature in SysML in which the nature of the relationship is expressed formally[3]. Even in its earliest incarnations, systems theory has included the representation of relationships in closed mathematical form where possible. It is relevant to this research in that a specified relationship may be coded within a function in a software simulation.

Constraints are a special type of *block* that describes relationships formally. Where express relationships algorithmically. They precision and detail to links among entities. They express in formal terms – mathematical or logical – the relationships between functional parameters.

4.4.3 Behaviours

SysML distinguishes behaviours as either continuous or discrete. Continuous behaviours are depicted as *actions* or *activities* which are higher level constructs enclosing groups of actions.

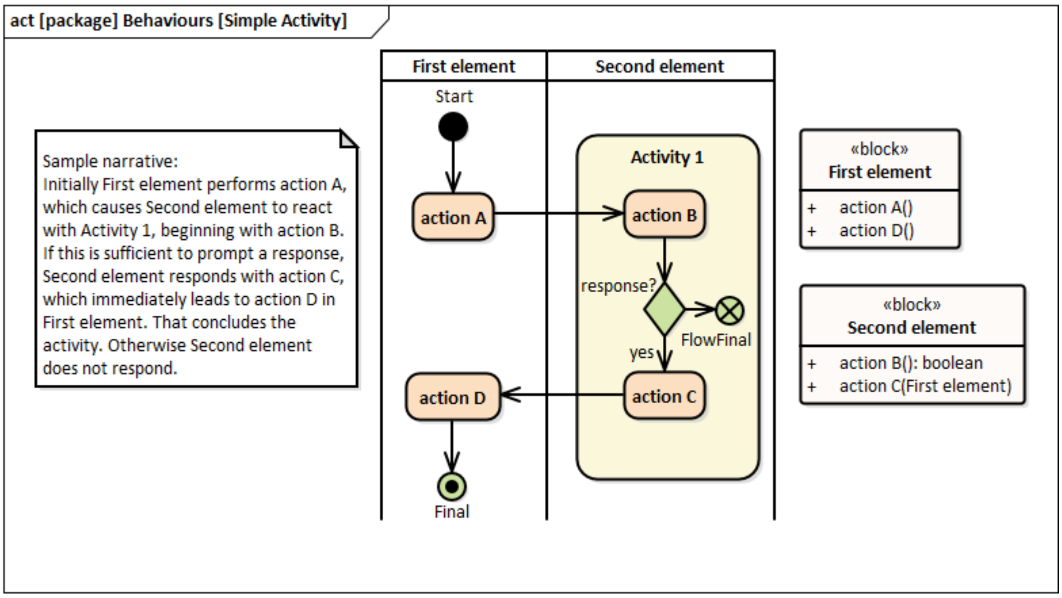


Figure 4.14: Events are produced by changes of state. Activity diagrams represent continuous changes (Author's own).

Activities

SysML expresses systems concepts in structural diagrams and in behavioural diagrams, chosen for the nature of the behaviour. Activity diagrams (Figure 4.14) depict behaviours as sequences, which make be marked by discrete events, or as continuous flows (which are implemented in computations as infinitesimally small discrete events in any case.) Activity diagrams translate a narrative and if necessary, allocate their actions and activities to elements, for future incorporation into the corresponding blocks.

State-charts

State-charts depict discrete behaviours as transitions triggered by external events and producing internal change in the values of one or more element properties (a reaction), and possibly producing another event at the edge of the system. The state-chart diagram (Figure 4.15) depicts changes in state for an element based on messages received. Each state represents a particular configuration of properties. Transitions among states mark changes in states external or internal to the element.

4.4.4 Translation process

The specification of the systems model adds a SysML ontology to the model as a new object. Its SysML style restates the narratives and networks of the themes object with SysML components. The process follows a textual

[3] The variant of the internal block is known as a parametric diagram when it includes constraints.

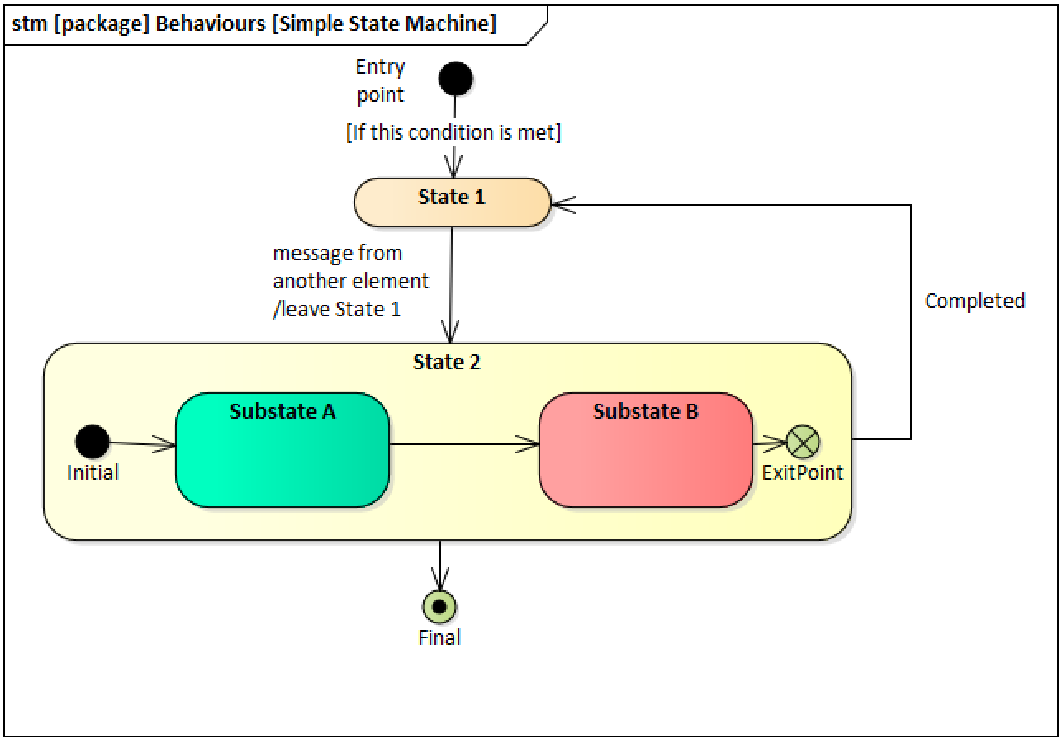


Figure 4.15: The outcomes of episodic events are represented in state-charts (Author's own).

and syntactic approach advanced by Rosenberg and Stephens (2013). This techniques maps syntactic elements in the narrative language to the structural components of SysML. Specifically, nouns describing elements are mapped to blocks, and adjectives mapped as properties. Verbs map to activities which, on decomposition, may map to actions as well.

In practice, the translation happens iteratively. As with the discovery of themes, the entities and actors are readily mapped to corresponding blocks, but it with the analysis of themes that the properties and activities associated with those blocks emerge.

This stage of the methodology begins with the analysis of themes in activity diagrams, that where necessary include swim lanes representing entities and in which the activities and actions are allocated.

4.4.5 Ontology Engineering

When SysML is used to describe a system *qua system*, it produces hierarchical and associative patterns that conceptualize the total entity and its constituent elements and layers. Borrowing from the information sciences domains, such a conceptualization is known as an *ontology*, a structure that is used later to name one of the styles in which the systems model is described.

> "[a]n ontology is a formal, explicit specification of a shared con-

ceptualization. Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and the constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine-readable. Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not private of some individual, but accepted by a group." (Studer *et al.*, 1998, p.185, quoted in (Gómez-Pérez *et al.*, 2004))

The term *ontology* has already been used in the review of model theory, and is now used to describe a structure. Conceptually, both uses are consistent; throughout the dissertation, the context will clarify which nuance applies.

4.4.6 Populating the ontology and the repository

As the structures and behaviours emerge in the translation, they are assigned as packages within the system design software, designed to reflects the hierarchical and behavioral shape of the ontology. These packages are described in detail in the application of the second version of the model (chapter 6).

4.5 Method 3: Software simulation development: implementing for exploration

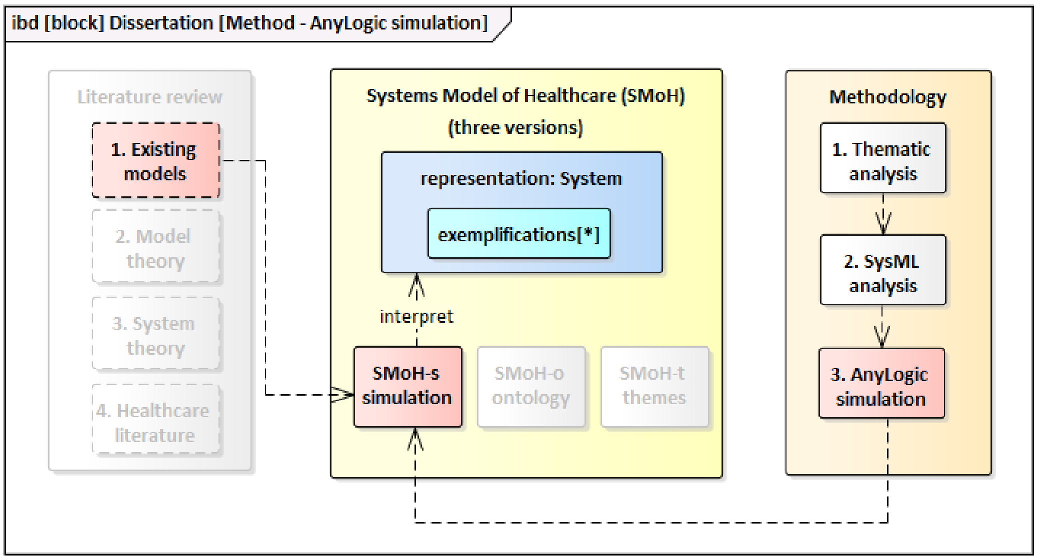


Figure 4.16: The third method implements a subset of the ontologic specification as a software simulation (Author's own).

The third method presents a description of the representation in a *simulation style* suited to interpretation by users with diverse professional skills. In this dissertation, the simulation implements constructs of the ontology description as a prototype computer simulation that supports interactive exploration and experimentation. The description is presented graphically and dynamically. As a rudimentary demonstration of the software approach, the simulation is designed to be configured to represent the healthcare system of a target country.

Implied in the research questions is the requirement that the representation be accessible by people of various backgrounds – policy makers, practitioners and researchers with interests and skills in healthcare policy and economics to name a few – whose backgrounds do not necessarily extend to systems engineering. In each case, the goal is to represent healthcare in styles that can be mapped readily to the special constructs in common use in their respective domains of expertise, yet maintain a common pool of mechanisms with which to interpret the representation of healthcare in its various dimensions.

With this intent, a healthcare system is represented in the code of a programming language, and visualized with the graphical resources of AnyLogic[4], a commercial off-the-shelf (COTS) simulation application. This provides a responsive and interactive computer based environment in which to explore, experience and explain how healthcare systems work.

4.5.1 Implementing a software application based on the ontology

The SysML specification, developed in with the second method, serves two purposes. On the one hand it provides a persistent repository in which to save the details of the healthcare system model in all its elements, properties, activities and events. This repository, however, is difficult to access for exploration and experimentation. Its second purpose, therefore, is to serve as a bridge to environments that are more conducive to human participation and interaction. In this research, the specification is readily transferred in the software language of AnyLogic, a commercial simulation application that supports computer based simulation.

The simulation is programmed using an approach known as Object Oriented Programming (OOP). For the purposes of the research and of this dissertation, it is sufficient to note that programming languages such as Java[5] represent objects as self-contained chunks of code with specified properties and behaviours. These chunks may be embedded in larger chunks until even-

[4] https://www.anylogic.com/

[5] . . . on which AnyLogic is based.

tually they are controlled by a master program. The resemblance between these structures of OOP and those of systems – their isomorphism – is the principal reason for choosing AnyLogic and Java as a simulation platform.

Some elaboration of terminology is in warranted. The master program is the *executable* that runs the overall simulation. The chunks are known formally as *classes*. They have *parameters* that hold values that are usually invariant, and *variables* that hold values that are expected to change from time to time when the simulation is running. The master program contains one or more classes and serves as an *environment* in which that class exists and functions. This corresponds to the *context* in which systems exist. Classes connect with other classes within environments.

AnyLogic additionally provides *Agents*, enhanced versions of classes as ready-made chunks, that already include means of using the environment for special types of communication. The platform also provides pre-programmed elements that implement constructs such as state charts, process flows and system dynamic elements including stocks and flows.

4.5.2 Simulation platform selection

AnyLogic is a Java based application with capabilities of implementing simulations as Discrete Event, System Dynamics and Agent Based models, either alone or in combination. Its software architecture is suited to implementing SysML language constructs, but in this respect it is not necessarily unique; most object-oriented applications share this feature. AnyLogic was chosen primarily on the basis of this author's familiarity with its development environment and syntax; although it also compares favourably to other platforms, critical assessment of available options was beyond the scope of this research.

4.6 Summary of the three methods

This chapter sets out the methodology for developing a systems model of healthcare – SMoH. The research applies three methods in three progressive phases (Figure 4.17). The first method, *thematic analysis,* analyses the broad landscape of healthcare knowledge that emerges in the literature review is analyzed to produce a thematic version of healthcare. This produces coherent sets of themes that can be traced back to the concepts and constructs of the real world, and that describe healthcare as a *system* in narratives and networks.

Applying *SysML analysis*, the second method uses a taxonomy of systems and the graphical elements of a systems language, to restate the themes and

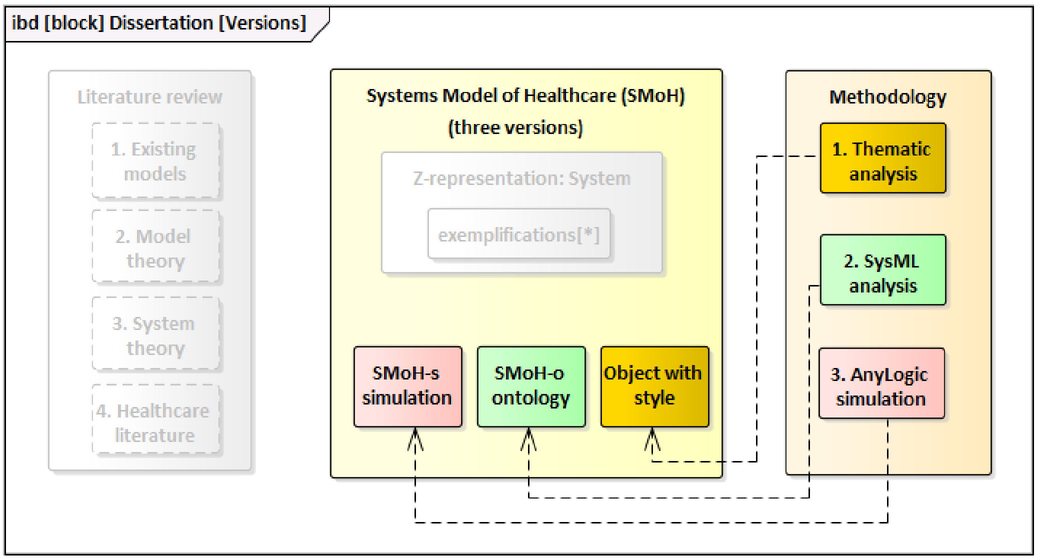


Figure 4.17: Progressing from domain expertise to an interactive implementation, the three versions of SMoH apply themes, ontology and simulation as interpretive styles (Author's own).

their entities as a formal set of specifications. This second version of the model is an ontology that is maintained as a data repository.

The third method, *AnyLogic simualtion*, uses a software platform to expose and explore the ontology as an interactive computer simulation. This version of the model uses a style that can be understood by users from diverse professional backgrounds.

4.7 Chapter summary

This chapter describes in detail the methodology used in this research. It begins with a review of the questions to be answered, followed by a summary of the requirements to be met by a systems model. The methodology is presented as a sequence of three methods: in the first stage, the published findings of experts are analyzed using thematic analysis. These qualitative findings, are interpreted as an ontology, specified using SysML, a graphical language designed for systems analysis and design. In the third stage, these specifications are implemented as a software simulation using AnyLogic, a commercially available platform.

The following three chapters report the research findings in the progressive development of these three versions of SMoH. Although they are reported sequentially, the application of the methods was recursive, demonstrating the open nature and the reproducibility of the methodology.

Chapter 5

Version 1: Systems Model of Healthcare as networked themes - SMoH-t

This chapter reports the findings of the first method of the research methodology. Following an overview of this version of the Systems Model of Healthcare (SMoH), the chapter first reports the entities that are found in healthcare systems in the literature, and then describes the activities that connect those entities, highlighting the mechanisms that explain how they function as systems at several levels. The pivotal role of change is addressed in a separate section, followed ultimately by a synthesis of the entities, constructs and mechanisms as a single, integrating pattern.

This version is created using the first method in the methodology (Figure 5.1). Thematic analysis applied to texts in the healthcare literature generates a representation of a healthcare system.

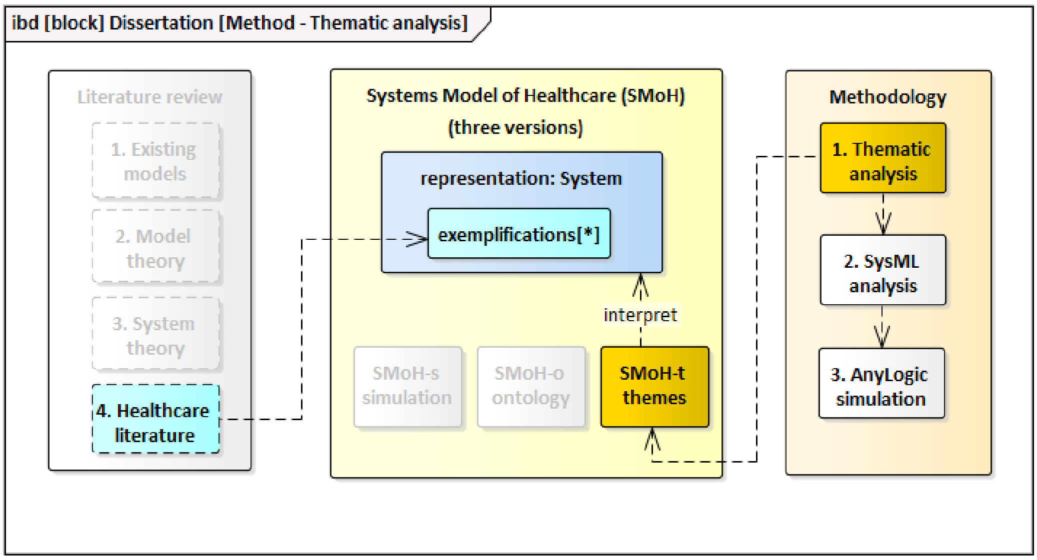


Figure 5.1: A representation shaped by expert knowledge found in the literature, healthcare is described with themes in SMoH-t, a theory based systems model (Author's own).

This is the version most closely linked to the real world of healthcare and is key to the use of surrogative reasoning with the model in all its versions. It focuses on the *representation* itself, the semantic component that conveys the systemic nature of healthcare, which is populated with synthetic entities and activities that are mapped to variables, constructs, propositions and theories observed in the real world of healthcare systems. These entities and activities combine as *mechanisms* (Machamer *et al.*, 2000) in the model to produce outcomes as *exemplifications* in the dynamic and causal contexts of the scientific model. Following the account of *explanation* proposed by Bokulich (2017) deduction from outcomes of these mechanisms may be inferred to the target, thereby serving the model's epistemic purpose.

This version of the systems model describes the representation with the narratives and network graphics of thematic analysis. Quoted texts are indexed to documents in the data set. The following quotation found in Andersen (1995) illustrates this treatment:

> "Among the predisposing characteristics, demographic factors such as age and gender represent biological imperatives suggesting a likelihood that people will need health services." (Andersen, 1995, Quotation 21:1)

The themes version of the model (SMoH-t) is fully contained and accessible as an ATLAS.ti project. Selected extended reports are attached in the Appendices (e.g., the data set in Appendix A and the codebook in Appendix B). In the following sections, selected exemplars demonstrate the scope and logic of the findings of the thematic version of the systems model of healthcare.

5.1 Overview of the systems model of healthcare, *thematic* version - SMoH-t

This first version of the Systems Model of Healthcare – SMoH-t – describes a representation of healthcare as a whole system using themes expressed in codes and networks. Synthetic entities and activities coded in the artificial environment of the model map to variables, constructs, propositions and theories reported in the literature. The themes formed and organized around these entities and activities reveal the representation first as closely related groups and then as a unified system. The overall epistemic purpose of the systems model – reasoning about healthcare in a target healthcare system – is realized by examining and hypothesizing about the entities and their behaviours as described by these themes.

Figure 5.2 previews the model. The representation of healthcare has its roots in micro foundations, depicted at the left edge of the diagram. It builds on entities and activities that are coded to represent the patterns in the real

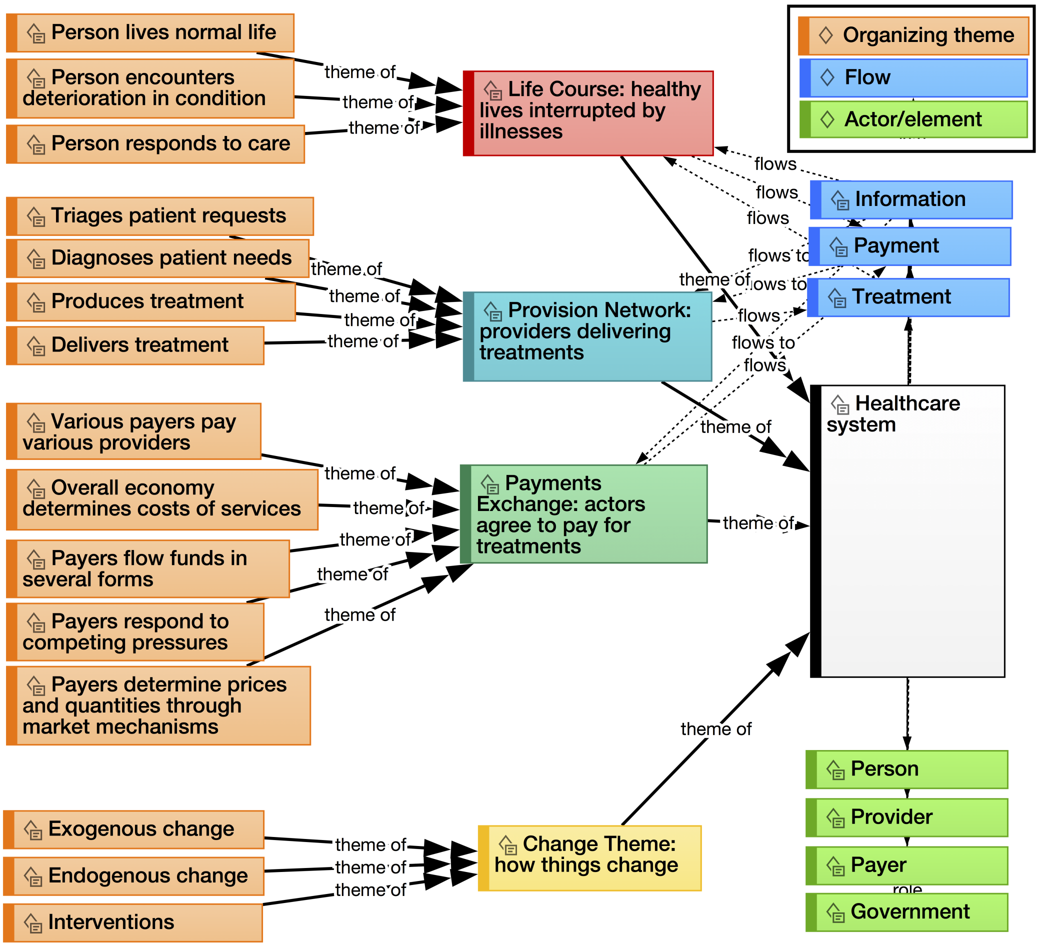


Figure 5.2: The network diagram shows a healthcare system with actors and themes in three global themes connected by flows (Author's own).

world of healthcare as described by domain experts. Basic themes describing these entities and activities as mechanisms are organized as broader themes. Taken together, these mid level themes explain what happens in three major domains, one where illness and treatments influence the health status of individual people, another where providers of various types deliver care, and a third domain in which providers are compensated through various mechanisms. The domains are linked by flows of treatments, information and payments as a single system of connected and mutually constraining themes.

The sections of this chapter describe how the analysis of the selected literature documents leads to this coherent structure.

5.1.1 Texts, codes, entities, themes and networks

The data set on which the analysis is based was selected from the review of healthcare literature (section 3.4).

The codes emerge through their assignment to texts in the documents of this data set. Their provenance in the quotations is illustrated in several

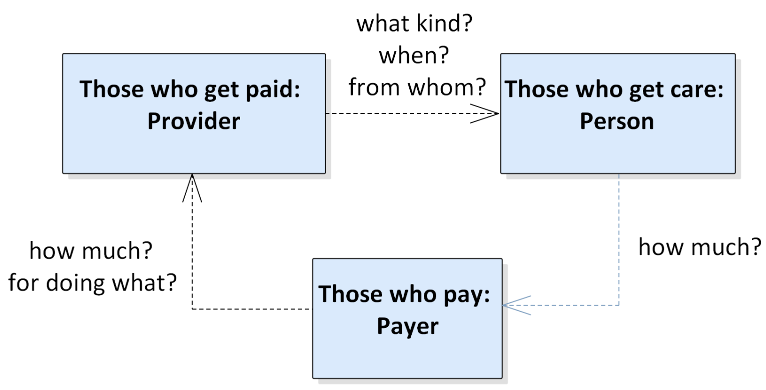


Figure 5.3: Understanding healthcare - adapted from Evans (2005)

network diagrams throughout this chapter. The codes are based on a template (Figure 5.3) originally suggested by a framework mentioned by Evans (2005, p. 283):

"...to understand how the system works one should examine

- who pays for care (and how much)?
- who gets care (what kind, when and from whom)?
- who gets paid (how much, for doing what)?"

They are classified as entities (e.g., actors, abstractions and their properties) and themes(e.g., activities that involve entities in various way). Figure 5.4 shows the code groups that evolved over the course of the analysis.

A meaning is attached each code as a brief comment, and its provenance in quoted texts or in other depicted in network diagrams. Details of all themes including tracing to quotations and texts are contained in the project data base. The codebook is attached in Appendix B. Each quotation identified in the text and in the figures by a reference to the relevant document and an index pair that identifies in the database both the document and the text fragment within that document[1].

The entities in the model include several types of actors, distinguished primarily by diverse properties and by their roles in healthcare. Abstractions belong to another group. These entities (e.g., illness, treatment, information) are distinguished not by physical attributes but by their influence on the states of other entities. As mechanisms they describe counterfactual dependencies, the activities are associated with the actors that are most closely involved.

Themes describing mechanisms of the change theme emerge as a product of the analysis. They are reviewed separately.

[1] E.g., (Author, Year, Quotation document number:quotation index)

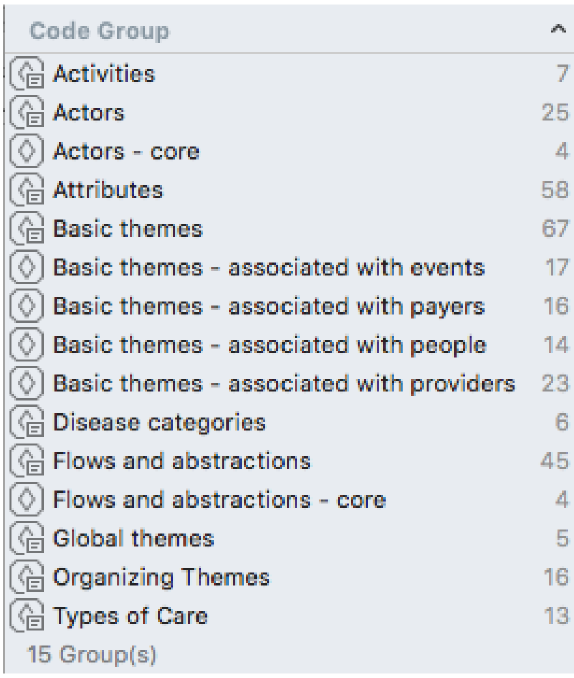


Figure 5.4: Codes assigned to quotations are grouped in ATLAS.ti as entities, attributes, activities and themes.

5.1.2 System entities as actors and abstractions

The entities of healthcare are relevant systemically from two perspectives – for their roles as participants in mechanisms, and for their observable properties of interest. The groups of entities are the first codes of interest – the actors and abstractions and their associated properties.

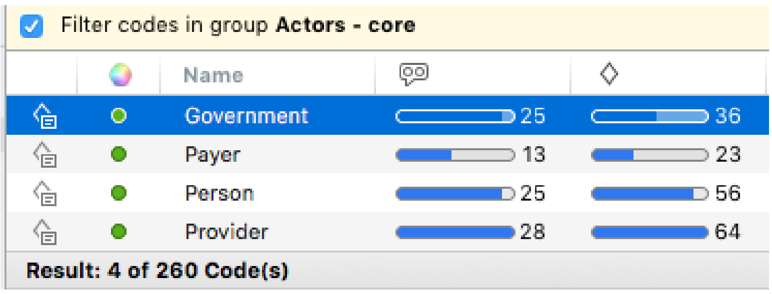


Figure 5.5: The code manager shows counts of quotations and links for Person, Provider, Payer and Government codes (Author's own).

Goals as properties that guide choice

By the taxonomy set out in subsection 3.3.9, a goal is a preferred outcome. At the system level, most countries express their goals in terms of the overall health of the population, with attainment of the goal to be realized in many instances by means of equitable access to appropriate professional care. The following fragments exemplify national healthcare goals:

> “It is worth noting that, the foundational goals of the SNS (Spanish national health system), set out in the Health Care General Act (1986), remain at the centre of the system, together with the challenge of achieving them. As a matter of fact, it is fair to argue that universal coverage with free access to healthcare, solidarity in public financing through general taxation, integration of different health service networks, political devolution, and region-based organization and the development of primary healthcare have seen considerable accomplishments over the years. But, at the same time, these goals are still an essential part of the current debate on the SNS.” (García-Armesto *et al.*, 2010, Quotation 15:10)

> “The goal of the health system is to protect the health of the population living in Portugal. The health system is the cornerstone to ensure that the provisions of the Constitution of the Portuguese Republic on rights to health are respected).” (Barros *et al.*, 2011, Quotation 11:1)

However, the roles of various individuals and groups suggest goals at other levels within healthcare. When Touhy notes the distinctions in the accountabilities of the various actor types – state actors, professionals and entrepreneurs – those distinctions evince different goals on the part of those people against which performance, and therefore accountability, is to be assessed.

> “In very broad terms, state actors function within systems in which those in command ultimately are dependent upon political support and therefore seek to accommodate a range of interests and opinions sufficient to maintain a coalition of support. Actors whose influence is based on access to private finance must respond to the demands of owners of private capital to realize rates of return comparable with those in other areas of investment. And professionals, who derive their influence from membership in the professional group, must maintain standing in the group by continuing to meet its evolving standards and norms.” (Tuohy, 1999b, Quotation 32:5)

Although not evident in the literature, the choices made by individuals and by organizations are made, either explicitly or implicitly, in the context of goals. For the purposes of this model of healthcare systems, such choices reflect health and financial status as personal goals, while net positive income is reflected in the choices made by providers and insurers. Professionals also seek alignment and recognition among their peers, while governments aspire ultimately to public approval of decisions and actions as expressed ultimately in voter support.

5.2 Actors

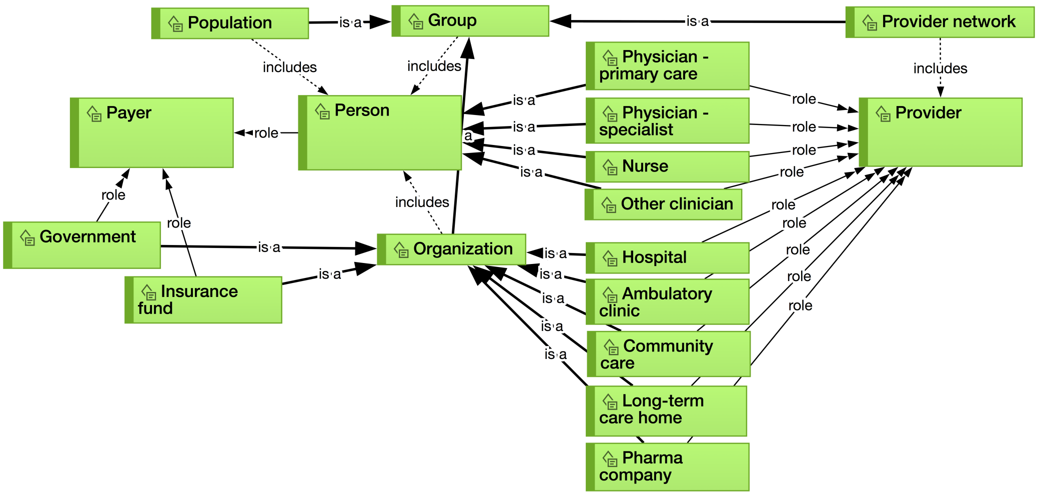


Figure 5.6: Most actors belong to four basic types – Payer, Person, Provider and Government (here depicted as a special Payer) (Author's own).

There are four essential actor constructs: *Person, Provider, Payer and Government*. The network diagram in Figure 5.6 shows each along with its variants. These are sufficient to describe the essential structures of healthcare systems. The diversity among their attributes and relationships account for the complexities of their behaviours and for the variations observed between the instances of each country's healthcare system. The Person is essential because restoring, maintaining and promoting a state of well being is central to the purpose and functioning of a healthcare system. The Provider plays a central role in delivering the services that support a Person's well being, while the Payer actor participates in compensating the Provider. The Government entity is prominently linked in many mechanisms and themes. Although it specializes attributes and behaviours of the Provider and of Payer entities, it is nevertheless included in the group of core actors.

5.2.1 Person as actor

The Person[2] entity shown in Figure 5.7 participates in mechanisms that are relevant to explaining how healthcare works. It arises explicitly in 25 quotations

[2]Throughout the dissertation, this actor type is coded as *Person* (pl. *Persons*.) This rather awkward usage is a reminder that, in the context of models and simulations, it refers to an artificial *representation* of one or more real people. However, to recognize that the representation is always of a human, *"she"* and *"her"* are used respectively as the relevant pronoun and possessive adjective.

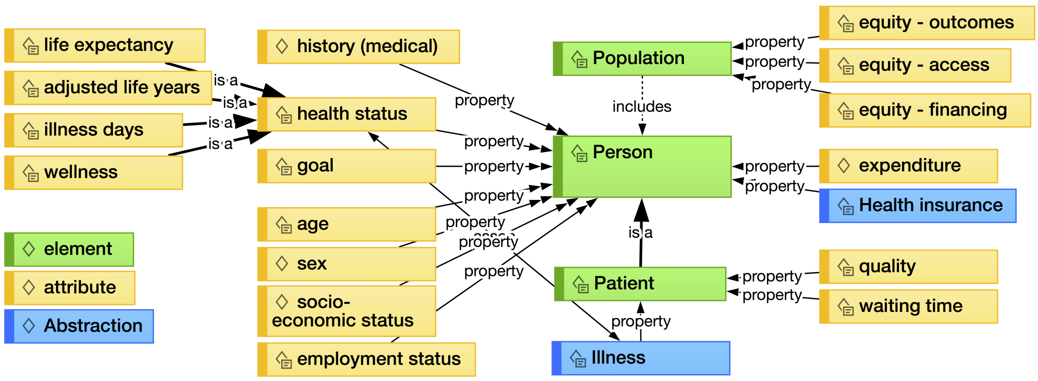


Figure 5.7: Based on frequency of occurrence,the properties of the Person are relevant to the mechanisms and outcomes of healthcare systems (Author's own).

and is linked to 56 other codes.

The state of a person *Person* is specified by several groups properties including, as fundamental demographic attributes, *age* and *sex*.

> "Among the predisposing characteristics, demographic factors such as age and gender represent biological imperatives suggesting a likelihood that people will need health services." (Andersen, 1995, Quotation 21:1)

Socio-economic status and *employment status* are both factors in the incidence of illness and in care.

The *Patient* code represents a Person entity in which *health status* is currently impaired by an illness. During the course of an illness and through episodes of treatment, a Person's experience is represented by a *quality* attribute, and delays or interruptions represented by a *waiting time* attribute, The potential effects of previous episodes of illness on current and future illnesses are represented by an attribute representing a *medical history* for the Person entity.

The involvement of the individual Person with the provision of care is indicated in part by accumulated *expenditure*, both in direct payments and in premiums paid for health insurance. Measures of *equity* represent the diversity of outcomes, access and financial support experienced by as Person's relative to the other members of the larger group. These properties although identified at micro level, are normally aggregated at the level of the population as a whole.

Finally, *goals* are specified for each Person entity to represent target states that combine values of individual properties. In the real world, such goals may not be explicit, but in the artificial context of a model, this construct is central to mechanisms that determine how choices are made.

Health status as a property

Health is a central construct in understanding and explaining healthcare. The World Health Organization (WHO) declaration articulates the concept as follows:

> "Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." (World Health Organization, 1946, Quotation 39:1)

Health status is a property of the Person and a primary measure of interest. The code arises in 45 quotations out of a total of 548 text fragments analysed. It is a core outcome indicator, expressed as one or more measures of survival, and in terms of wellness and illness free days.

Life expectancy is an estimate of remaining years of life for a representative Person at a given age, based on current and historical records of mortality. In the literature it is referenced as a measure of outcome for an entire region. For instance, in Germany:

> " . . . most age-standardized death rates decreased substantially between 1990 and 2011. This positive development is also reflected in the increases seen in life expectancy at birth and in the other age groups" (Busse and Blümel, 2014, Quotation 3:27)

Life expectancy is defined in the literature as

> ". . . the number of years that a person at a given age can expect to live in good health taking into account age-specific mortality, morbidity, and functional health status." (Salomon *et al.*, 2013, Quotation 52:1).

Within the codebook, the property is defined as an expected value. It is commented as

> *Lifespan as estimated at a given age. Interpreted as longevity in the context of the human capital model.*

Adjusted life years is an alternative indicator of survival, measured in terms of years of life deemed lost or impaired due to illness, and in particular to occurrences whose impact could have been reduced if appropriate treatment had been provided.

> "the sum of years of life lost due to premature mortality (YLL) and years lived with disability (YLD)." (Murray *et al.*, 2013, Quotation 53:1).

Within the codebook, the code is commented as:

> *Estimated negative impact of an illness on longevity. The various methods estimate the number of years of unassisted living that have been lost due premature death, or impairment of the quality of normal life due to the immediate or continuing effects of the illness.*

Life expectancy and adjusted life years, as statistical measures of survival, are calculated *a posteriori* at the aggregate level of populations and groups. Country-wide statistics on life expectancy and avoidable mortality are readily and consistently gathered at a national level (OECD, 2017). Since both categories of survival measure are based on population aggregates, they reflect prevailing externalities of society in general such as social determinants of health, and available health technology – rather than intrinsic properties of the individual Person.

These measures of survival have explanatory value in that they can be causally linked to mechanisms in healthcare, such as the influence of social conditions and of clinical technologies in avoiding premature death. As properties of a Person during a lifetime, they are expressed as probabilities, and their inclusion in specifying mechanisms is limited to the statistical boundaries of those probabilities.

Measures of health status during a lifetime are difficult to observe in the real world. Surveys gather self-reported health status, but these measures typically lack objective calibration, are essentially subjective and are influenced over time by memory and personal disposition. *Health* has been proposed as a composite measure of health status in the synthetic world of a model:

> "In my model, health - defined broadly to include longevity and illness-free days in a given year - is both demanded and produced by consumers. Health is a choice variable because it is a source of utility (satisfaction) and because it determines income or wealth levels." (Grossman, 2000, Quotation 18:4)

In this research, *wellness*, is used as a logically equivalent term for Grossman's *freedom from illness.* It is a measure of health status that serves as a salient indicator of the current state of an individual. As a companion measure, *illness-free days* is an accumulating numerical construct that can be modified[3] to produce a consistent measure of lifetime.

With appropriate assumptions, this allows representation, for instance, of Persons whose level of illness/wellness would warrant treatment, but who do not request it. In the real world of healthcare, such people remain hidden from observation, but in the model context their outcomes can be observed as consequences of simulated policy changes.

Illness as an abstract construct

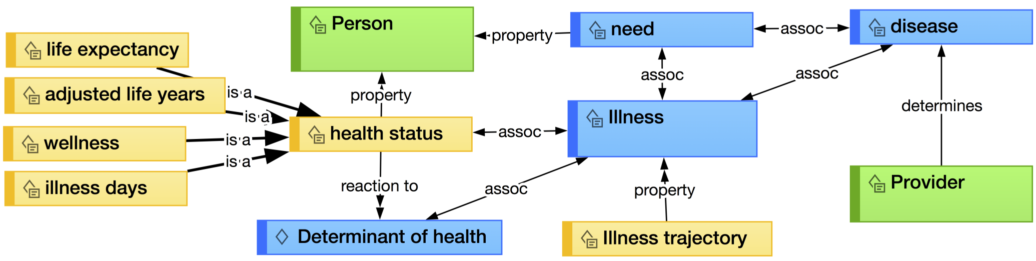


Figure 5.8: Episodes of illness are at the heart of healthcare (Author's own).

The Person's health status property, and wellness in particular, is associated with *illness*, another essential construct in the larger context of a healthcare system. Illness is a central concept of healthcare (Figure 5.8). It is an abstraction in that its properties and dynamics are observed only in the context of an individual person. The code is attached to 30 quotations and is linked to 27 other codes.

Illness is the antithesis of wellness. It is characterized by its negative impact on an individual's wellness, and by the duration of that impact. As a representation in the model, the occurrence of an illness is marked when its impact on wellness exceeds a person's threshold of independence and is sufficient to warrant seeking professional assistance.

There are factors in society at large that influence the occurrences of illnesses in the lives of individual Persons. For example,

> "...Danes with no vocational training had a mortality rate that was almost 80% higher than that of Danes with a higher level of education. Even when smoking, drinking and lack of exercise were adjusted for, the mortality rate of those with no vocational training was still 50% higher. This was found to be largely a result of less favourable living conditions, unhealthier work environments

[3]... as a ratio of days lived so far, for instance.

and a much higher mortality rate for permanently unemployed people." (Olejaz *et al.*, 2012, Quotation 8:26)

"Health is impaired by unemployment and circumstances threatening impoverishment; a low awareness of the importance of health; harmful effect of air pollution and noise; tobacco and consumption of alcohol, as well as harmful eating habits and a lack of exercise; overweight; high blood pressure; and fat metabolism disorders. These determinants, which are of particular significance for chronic disorders, also reveal numerous possibilities for prevention and health enhancement." (Busse and Riesberg, 2004, Quotation 3:30)

The *determinants of health* code is described as follows:

> *Constructs as properties in and of the context of society at large that are factors in the incidence and prevalence of illness. Changes in social determinants are exogenous to the systems of healthcare.*

In reviewing the healthcare literature section 3.4.2, four terms related to reduced wellness were distinguished – *illness, disease, sickness* and *need*. Of these, *illness* is selected as the salient construct in the model, using Boyd's definition:

"... a feeling, an experience of unhealth which is entirely personal, interior to the person of the patient. Often it accompanies disease, but the disease may be undeclared, as in the early stages of cancer or tuberculosis or diabetes. Sometimes illness exists where no disease can be found." (Boyd, 2000, p.9, document 46:2)

He defines *disease* as:

"..a pathological process, most often physical as in throat infection, or cancer of the bronchus, sometimes undetermined in origin, as in schizophrenia. The quality which identifies disease is some deviation from a biological norm." (*ibid*, p. 9, Quotation 46:1)

Sickness is

"the external and public mode of unhealth. Sickness is a social role, a status, a negotiated position in the world, a bargain struck between the person henceforward called 'sick', and a society which

> is prepared to recognize and sustain him."(*ibid.*, p. 9, Quotation 46:3)

Need is distinguished from both concepts:

> "The need component refers to illness level, which is the most immediate cause of health service use. The need for care may be either that perceived by the individual or that evaluated by the delivery system." (Aday and Andersen, 1974, Quotation 38:1)

Boyd's use of *personal unhealth* maps to the concept of *wellness* as a personal attribute.

Illness follows a trajectory

In the real lives of individual people, illnesses are experienced as symptoms that persist over periods of time. For example, individual encounters with illness are inferred from the accounts of Health Systems in Transition that provide exemplars of the stages in treating illness episodes. These examples also indicate that the duration of an illness is a function of the Person's characteristics and of the treatment responses provided within the healthcare system.

> "In Sweden, a woman in need of a hip replacement would typically take the following steps: The first visit would be with the primary care provider where she has chosen to be registered. . . " (Anell *et al.*, 2012, Quotation 9:4)

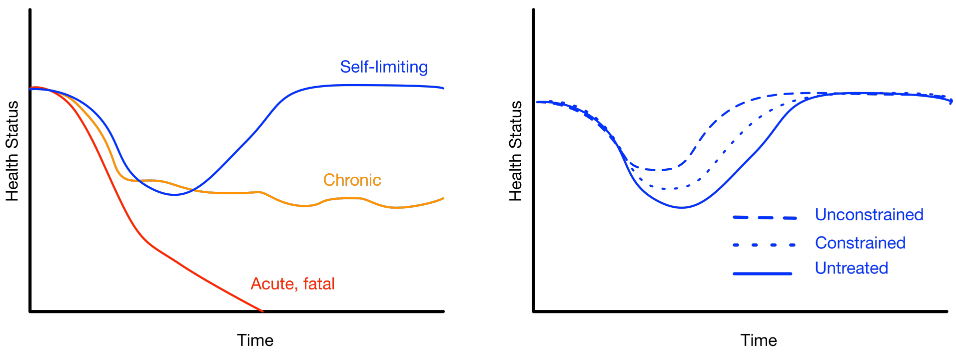


Figure 5.9: Illnesses follow trajectories over time, by both their nature and their treatment, adapted from (Donabedian *et al.*, 1982).

However, as illustrated in Figure 5.9, for representative purposes and in the interests of parsimony, they are distinguished by a limited set of categories as *self-limiting,* indicating a temporary reduction in wellness, followed by a steady recovery to full wellness over a period of weeks; *acute,* characterized by sudden and pronounced deterioration, continuing in days to death in the absence of timely intervention; and *chronic*, characterized by a gradual decline that continues to death over months without intervention.

> "We include future expected health in our assessment of a person's health status by taking the sum over time of expected health states in the future, where expected health in a future year is the probability- weighted sum of possible health states in that year." (Donabedian *et al.*, 1982, Quotation 40:2)

> "We need to know a great deal more about the course of illness with and without alternative methods of care. To compare the consequences of these methods, we need to have more precise measures of the quantity and quality of life. We need to understand more profoundly the nature of the interpersonal exchange between patient and practitioner, to learn how to identify and quantify its attributes, and to determine in what ways these contribute to the patient's health and welfare." (Donabedian, 1988, p.1748, Quotation 22:2)

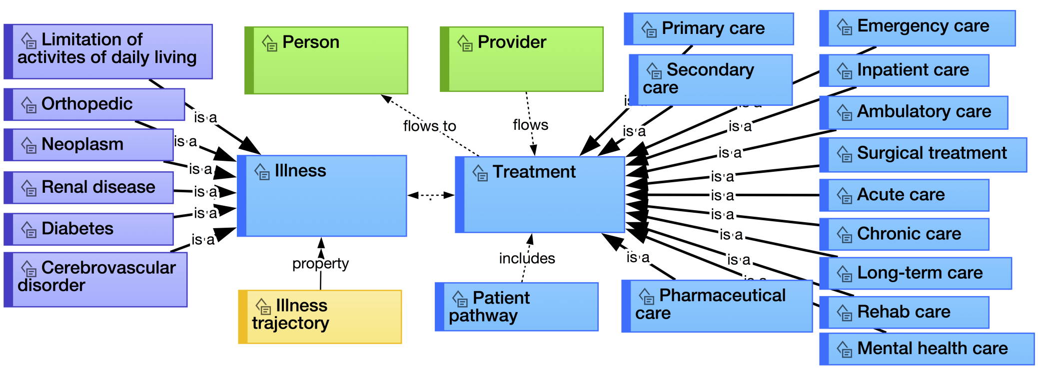


Figure 5.10: Illnesses and treatments are closely related (Author's own).

The concepts of wellness, illness and treatment are related, as shown in Figure 5.10. From time to time, a Person encounters an illness that adversely affects her wellness, contributing to a need that can be met by a provider of care. The Person reacts to treatment received, with corresponding restoration of wellness. Each of these coded concepts is developed in detail in later sections; the pattern they represent is pivotal in representing healthcare here.

Illnesses may be clustered in groups that share similar impacts on wellness. Clinical expertise maps treatments in various combinations to those illness types.

The respective codes are summarized as follows:

Illness

> *Illness is a reduction in wellness, a benchmark measure of unimpaired health status. It is marked by a deviation from a baseline value, caused by an external event. The risk of illness is a function of factors endogenous and exogenous to the individual Person, but the precipitating event is essentially stochastic.*

Trajectory

> *For every Person, each illness follows a trajectory of impairment over time. In the first instance, every illness has a characteristic trajectory observed reported in the literature. It is modulated in particular by the effects of any treatments received. For representation, the trajectory may be stylized to a limited set of trends, distinguished by magnitude, dynamic shape and duration.*

5.2.2 Provider as actor

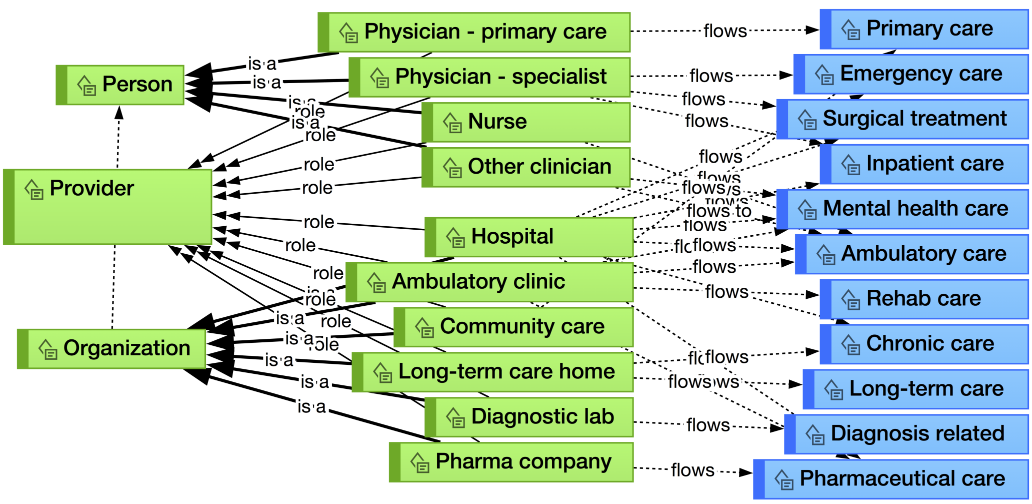


Figure 5.11: Providers are distinguished by the care they provide (Author's own).

The WHO defines a health system as one that "... include(s) all the activities whose primary purpose is to promote, restore or maintain health." (WHO, 2000, Quotation 51:5)

The *Provider* code generalizes the role of individual actors who have the capability of restoring health and the capacity to deliver treatments to individual

Persons. The several types of Provider[4] are distinguished by their properties (resources and assets) and their behaviours (skills and processes). Each has a capacity that is depleted when resources are allocated to a treatment package, and replenished periodically as funding is received. This diversity of type and of treatment provided is shown in Figure 5.11.

Provider types and attributes

A Provider's state is expressed in terms of services delivered, of resources consumed and replenished, and of expenditures incurred. Performance is measured using relative levels of these quantities, as measures of *technical* and *allocative efficiency*. Governance reflects ownership either as a *public or private* institution, and service may be delivered on a *public* or *private* basis. Every Provider works to one or more goals– economic, professional and social – and according to priorities, determined either by personal values or by the governance of organizations as established and updated from time to time.

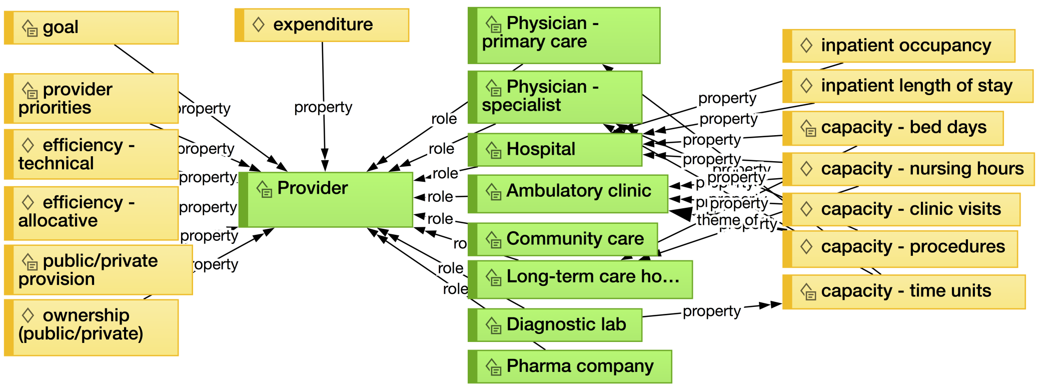


Figure 5.12: Most Provider attributes are common to all types; capacity is unique to the associated treatment (Author's own).

Extending to specialized roles, Figure 5.12 shows the attributes associated with Providers in common and with their several types[5].

The Provider codes assigned to the people and organizations distilled from the literature are listed alphabetically in Table 5.1 representing the diversity of participants involved in healthcare systems.

[4]As with the usage of Person in the previous section, the term *Provider* is applied here to indicate a concept that captures core properties and activities of the people and organizations that provide treatment and care to patients.

[5]This diagram lists Providers who usually function autonomously. Nurses usually provide their professional services within Provider organizations. This may change in future, with the introduction of revised regulatory and management structures that modify the autonomy of various healthcare practitioners.

Table 5.1: Provider actor codes

Name	Comment
Ambulatory clinic	Provider of specialist consultation on day basis.
Community care	Organization providing care in home.
Diagnostic lab	Provider of imaging and laboratory test services.
Employer	Occasional provider of insurance.
Government	Legal authority of the state exercised by elected representatives.
Hospital	Organization providing inpatient care
Institution	Alternative term for organization providing care in designated facility.
Long-term care home	Organization providing residential care with support for daily living.
Manager	Person in organization with responsibility for leading employees.
Nurse	Professionally qualified healthcare provider usually practicing as an employee of a provider organization.
Organization	System of people defined by a common goal.
Other clinician	Person who is a healthcare provider other than a physician or nurse.
Pharma company	Organization providing pharmaceuticals.
Physician - primary care	Provider of standard medical treatment in the community.
Physician - specialist	Provider of advanced treatments.

Source: From the thematic analysis of 52 texts, author's coding

Physicians

Physicians perform pivotal roles in healthcare systems. Some of the actions they carry out, such as diagnosing disease conditions and prescribing medical and surgical interventions, are in most jurisdictions reserved to certified practitioners. Their practice types are distinguished by the scope of illnesses and diagnoses they manage. A *Physician - primary care* is a Provider of standard medical treatment in the community. This actor is typically the initial point of contact when a person encounters an illness. She provides diagnosis based on symptoms and may coordinate with other specialist physicians who provide diagnostic services. The primary care physician uses and depletes units of professional time as *capacity* in consultation. She may also deliver care in the form of a prescription for pharmaceutical treatment or a referral to a specialist. In some cases this referral may be admission as an inpatient to an acute care hospital.

A *Physician-specialist* delivers treatment under conditions similar to those of the primary care physician but restricted to certain clinical systems and diagnostic and therapeutic approaches. Once again the capacity consumed is professional time, but associated with physical facilities such as clinics and surgical suites.

Organizations

Hospitals and *Ambulatory clinics* are Provider organizations made up of several clinical and administrative individuals whose collective activities deliver more complex treatments. Hospitals are distinguished from clinics by their added provision of continuous hours of nursing care and of hotel services provided as inpatient bed capacity. Provision of this type of care is measured both as length of stay for a given Person, and the degree to which the total bed capacity is utilized over a given period (occupancy). *Community care* organizations provide clinical care typically in homes of individuals. *Long term care homes* provide residential care similar to hospitals, but with a considerably lower capacity for nursing care. Unlike in hospitals, the duration of a person's stay in long term care is typically associated with remaining years of life.

5.2.3 Payer as actor

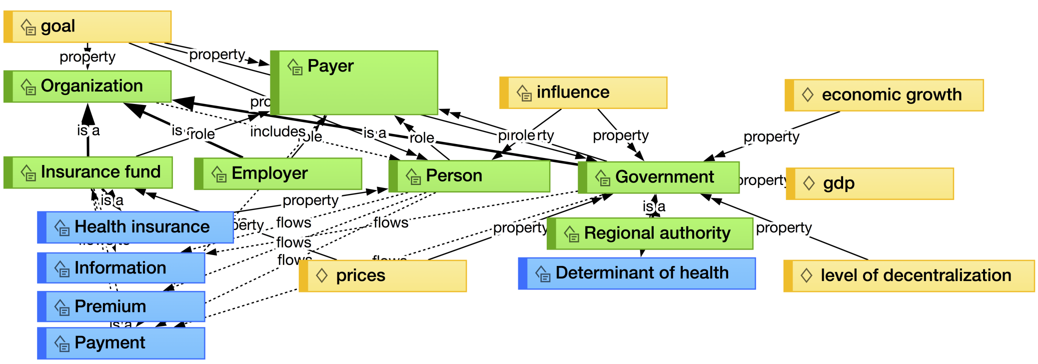


Figure 5.13: Four main actors (insurance provider, employer, person and government) behave as Payers (Author's own).

Government, at various levels of decentralization or regionalization is primarily a regulator that constrains the behaviors of other participants but is constrained for its part by the collective sanction of the population at election time. Insurance firms sell contracts to individuals directly or indirectly through employers. The price is set and updated periodically based on prices paid to providers and on historical revenues and market share.

Government

The *Government* entity is primarily[6] a Payer, providing funds either directly or through other Payers. As a Payer, this entity also sets boundaries and conditions to those payments, but with the authority of the state, the government also plays a superordinate role in establishing regulations that impact the behaviours of Providers – e.g., licensing to operate and to practice, and of Persons – where availing of personal health insurance is mandatory.

> "In 2006, the government published a White Paper, Our Health, Our Care, Our Say (Department of Health 2006c), which proposed that some hospital services be switched to community settings." (Boyle, 2011, Quotation 10:3)

> "The Dutch government aims to introduce small reforms that further enable managed competition in the system. Other government aims are to strengthen the position of the patients, to further strengthen primary care, to introduce electronic patient records, and to implement further changes to mental and long-term care." (Schäfer *et al.*, 2010, Quotation 14:18)

The Government code is described in this analysis as:

> *Government is a unique actor associated with a healthcare system, as a payer that funds treatments, and as a regulator with the legal authority of the state to enforce rules exercised by elected representatives who rely for their authority the renewing mandate of the population.*

Insurance firms

In some jurisdictions, health insurance is provided and administered by commercial firms that operate as corporations accountable to governing bodies for economic performance and for other goals. Insurance firms compete in markets, both as purchasers of services from Providers on behalf of policy holders, and as vendors of insurance policies to Persons and to employers on behalf of those Persons.

> "Market structure is another important feature for competition. The number of plans a consumer typically faces is greater than five in four countries, while three insurers cover the whole market in the

[6] In some jurisdictions, the state is also a Provider of treatment.

> Slovak Republic. The concentration of the primary basic health insurance market is the highest in the Czech Republic where the top insurance fund holds 60% market share… It is relatively high in the Netherlands and Slovak Republic, where the top three insurers account for 75% and 100% of the market, and lower in Germany and Switzerland. In Switzerland, health insurers operate at the cantonal level while in other countries insurers mainly operate nationwide." (Paris *et al.*, 2010, Quotation 37:7)

Statutory health insurance

In some jurisdictions, healthcare costs are underwritten by corporatist entities meeting requirements for statutory health insurance (SHI), a mechanism in which Persons contribute to funds on the basis of their employment, trade or profession. These organizations differ from commercial insurance firms in that their mandates are primarily to meet the costs of services provided rather than earning returns for shareholders. The state usually augments funding for marginalized groups.

> "There is SHI, which, under various schemes, currently covers almost 100% of the resident population. The delivery of care is shared among private, fee-for- service physicians, private profit-making hospitals, private non-profit-making hospitals and public hospitals." (Chevreul *et al.*, 2010, Quotation 13:2)

> "Although SHI dominates the German discussion on healthcare expenditure and reform(s), its actual contribution to overall health expenditure was only 57.4% in 2012. Altogether, public sources accounted for 72.9% of total expenditure on health, with the rest of public funding coming principally from statutory long-term care insurance (Soziale Pflegeversicherung)." (Busse and Blümel, 2014, Quotation 3:7)

5.3 Entities that flow

Figure 5.14 illustrates unique, recurring constructs that are grouped as *flows*. These entities are generated by certain elements and exchanged with others as implementations of their relationships. Three major types of flow emerge: *treatments* delivered by Providers to Patients (Persons), *payments* delivered by Payers to Providers, and *information* in various forms to support the other two types and exchanged among several actors. Treatments deplete a Provider's

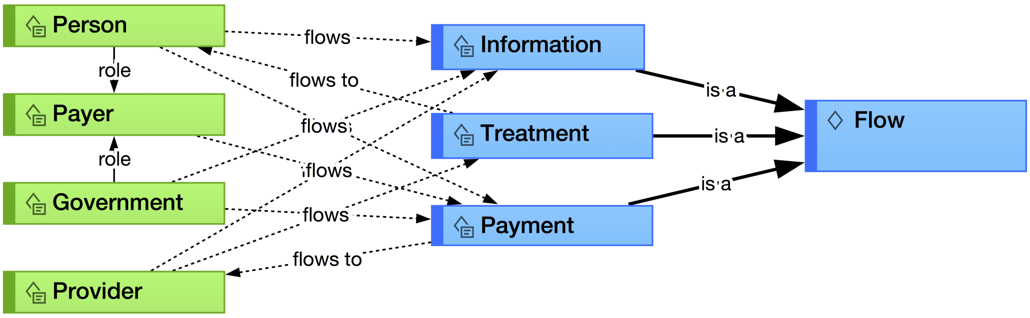


Figure 5.14: Information, treatment and payments are exchanged as flows between actors (Author's own).

clinical resources, and Payments deplete a Payer's financial resources. Information flows without depletion and may be accumulated and preserved by all parties to its exchange.

These flows are essential to the systemic nature of healthcare because they reflect the relationships that concurrently influence the various outcomes of interest that are the goals of healthcare. Their inclusion in the model at the top level is one of the main contributions of this research in that they represent the mechanisms that that bind the essential entities in healthcare as a *single, coherent system.*

5.3.1 Information flow

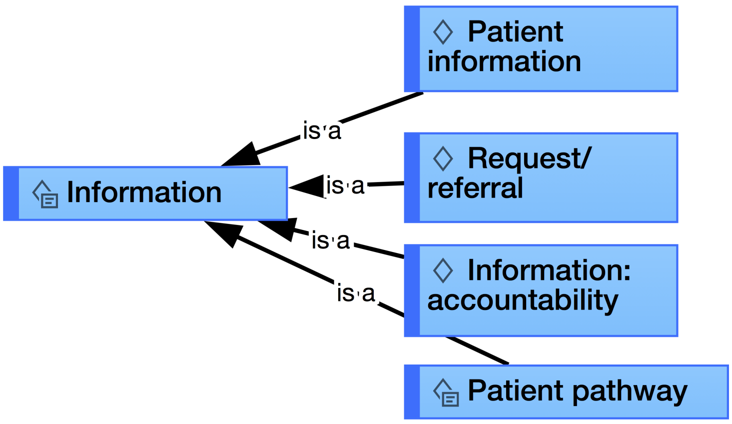


Figure 5.15: Four types of information flow between actors (Author's own)

The first of the three types of flow, *inforamtion*, comes in four forms. The first, as shown in Figure 5.16 is Patient information that flows between Persons and among Providers, particularly as a representation of the encounters that inform Providers and that enable diagnosis and referral to other Providers. The remaining types of information flow relate to the communication processes among providers that support the coordination of services when treatment requires contributions from more than one source. It is notable that flow of patient information does not deplete its source. It can be replicated and preserved as a persistent record, particularly as a history of past events and encounters.

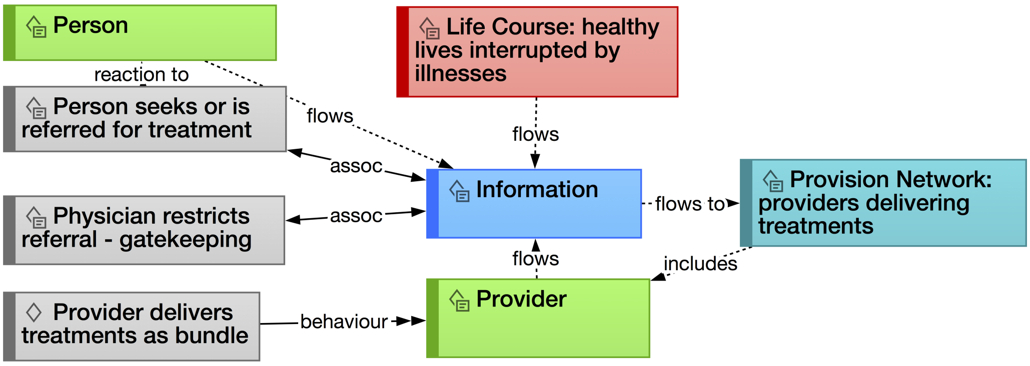


Figure 5.16: Requests and referrals flow from Person to Provider (Author's own).

5.3.2 Treatment flow

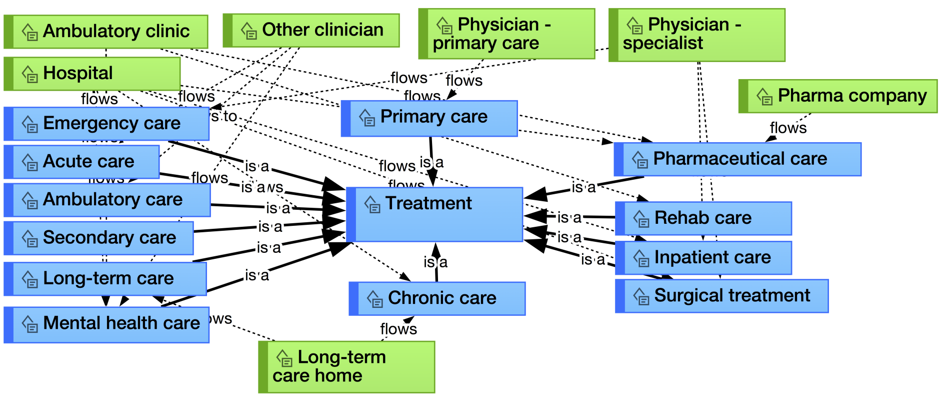


Figure 5.17: Treatments of various types flow from Providers (Author's own).

Treatments are organized sets of resources, as illustrated in Figure 5.17. Provision of treatments is the core flow of healthcare systems. Each treatment can take various forms, as determined by the physician or other provider. Production and delivery of a treatment depletes one or more of the Provider's resources. Note that many providers may contribute treatment to a Person during one episode of illness. This is reflected in inclusion of a referral (as information flow) attached to a particular treatment, representing a hand-off of care from that provider to another in the network.

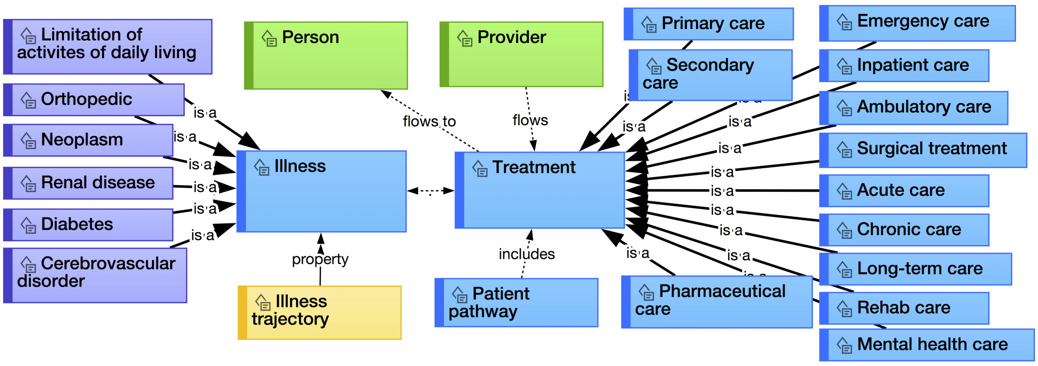


Figure 5.18: Treatments are mapped to illnesses (Author's own).

The linkage between treatment and illness type is depicted in Figure 5.18. The treatments are mapped to illnesses, by individual practitioners. These mappings are addressed in clinical research and assessed in technology assessment studies, often using micro simulation models as described in (subsection 3.1.7). Within the model they are conceptual and parsimonious.

5.3.3 Payment flow

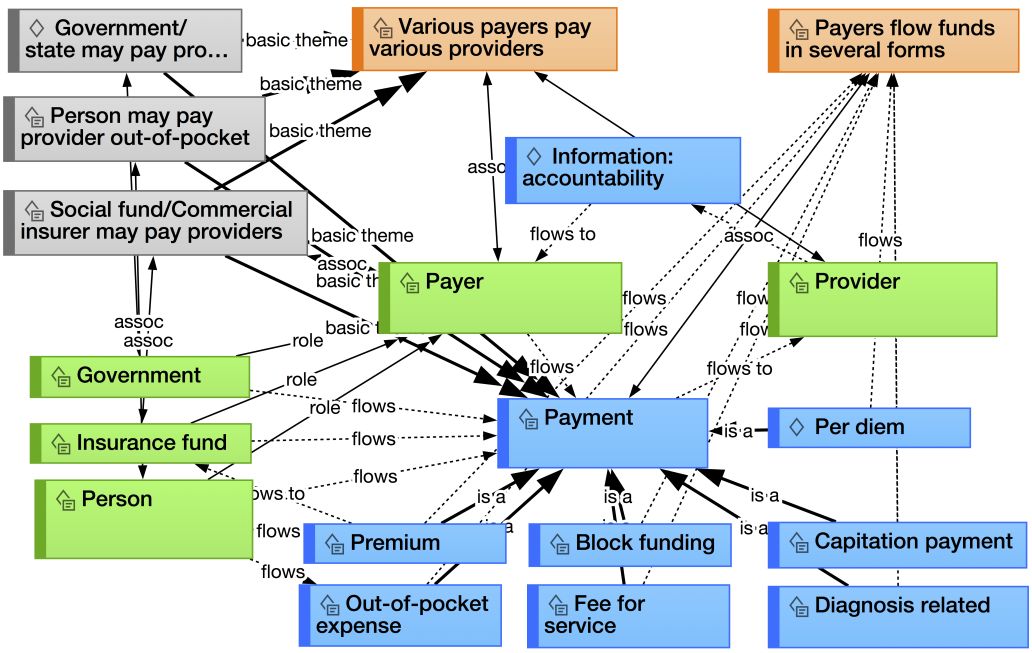


Figure 5.19: Payment for treatments takes several forms, and flows from various financial sources (Author's own).

The flows of payments from Payers to Providers close loops formed by the flows of information and of treatment (seen in Figure 5.19). Fundamentally, the amount of payment is closely related to the quantity and type of treatment delivered by Providers, but the underlying basis on which those payments are computed is also relevant to the understanding of how the relationships between payments made and treatments delivered.

> "Payment methods are distinct from payment levels. Although payment methods certainly affect growth in spending over time, there are many alternatives for paying providers for any given level of spending. (Methods and levels are typically negotiated between providers and commercial payers and are set unilaterally by government payers.) These alternatives can be understood as combinations of the 8 basic methods. The essential difference among methods is the unit of payment, which divides financial risk between payer and provider." (Quinn, 2015, Quotation 26:1)

Payment represents money in the accounting sense of accrued assets and liabilities. The method of payment is one of the properties that most prominently distinguish healthcare systems from one another, as noted by the following quote:

> "This has meant fundamental changes in the roles of patients, insurers, providers and the government. Insurers now negotiate with providers on price and quality and patients choose the provider they prefer and join a health insurance policy which best fits their situation. To allow patients to make these choices, much effort has been made to make information on price and quality available to the public." (Schäfer *et al.*, 2010, Quotation 14:7)

5.4 System activities as themes

The basic themes are the second group of interest in the groups of codes (previously illustrated in Figure 5.4). These capture the mechanisms that function at the lowest level of the model, exposing activities, the entities that perform them and the outcomes they produce. As suggested by Attride-Stirling (2001), the themes are gathered in related groups. As a first step in sorting, this grouping is realized by selecting within the software application the codes that co-occur with each of the Actor codes. This process identifies the basic themes associated with each one. It also gathers details of attribute and other codes associated with the core actor entity. These are the microfoundations of healthcare.

In the next phase of the account, basic themes are grouped on the basis of their association with three[7] of the core actors – the People, Providers, and Payers. These themes capture and reconcile meanings expressed or implied in quotations extracted from various documents in the data set. The resulting interpretation of those meanings are contained in comments attached to the theme. The third level of analysis organizes these basic themes in networks that capture at a higher level the broad functioning of each of the groups. In a final level, network analysis consolidates each of these groups as global themes, and links them through flows.

5.4.1 Basic themes associated with Persons

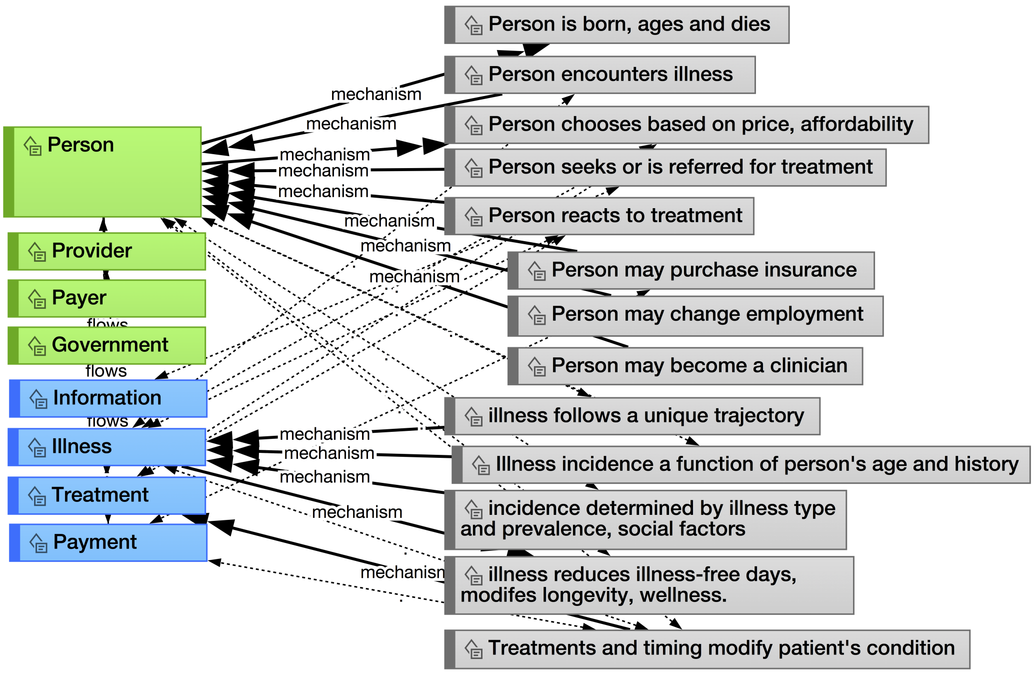


Figure 5.20: The first set of basic themes, mechanisms, attributes and abstractions co-occur with Person actors (Author's own).

As a first step in sensemaking, the sets of basic themes are sorted on the basis of the actors involved. Those associated with the Person code are shown as a network in Figure 5.20. A selection of some is reviewed here in detail.

Person is born, ages and dies

The concept of an individual life time is a fundamental and axiomatic theme in healthcare. It is expressed in quotations that describe life events for individuals, most often as aggregate rates for the population. The span from birth

[7]In this analysis, the themes associated with Payers are sufficient to reflect the dual roles of government identified in subsection 5.2.3.

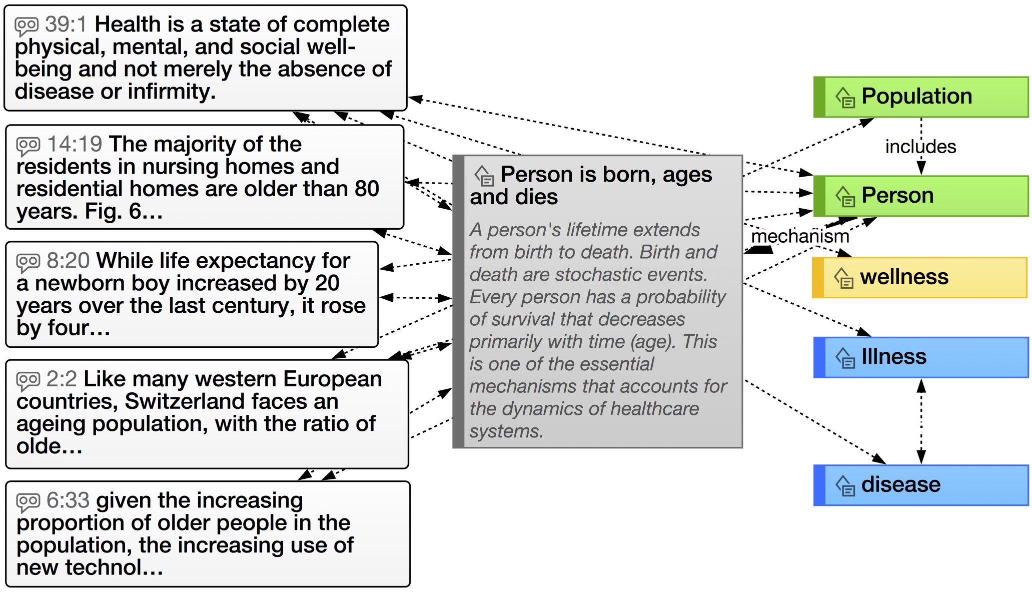


Figure 5.21: Birth, aging and death of a Person are fundamental themes in healthcare (Author's own).

to death is inferred from references to life expectancy at birth, and to factors that accelerate mortality in the presence of illness and disease. Figure 5.21 illustrates the linkages among this theme and its associated quotations and entities.

> "While life expectancy for a newborn boy increased by 20 years over the last century, it rose by four years for a man aged 50 years or older. Declining mortality rates among children, young and middle-aged people largely reflect a decline in infectious diseases, including tuberculosis. In the 1930s, 60% of those dying from tuberculosis were aged between 15 and 44 years, thus belonging to the workforce..." (Olejaz *et al.*, 2012, Quotation 8:20)

The meaning of the theme is also inferred from changes in lifespan as referenced in growing numbers of an aging population.

> "Like many western European countries, Switzerland faces an ageing population, with the ratio of older people to people of working age having risen to 26.1 per 100 (although this is still below the EU average of 28.1)" (De Pietro *et al.*, 2015, Quotation 2:2)

The individual Person is a central actor in a healthcare system. In this respect, the model adopts a basic structure similar to that of microsimulation models. The addition and removal of individuals to and from the model is a fundamental mechanism that results in changes to the rates at which other mechanisms occur. The Person actor has been described earlier in the chapter.

The events of birth and death are essential mechanisms in the overall dynamic of the model. Aging – living a life – is not itself a mechanism. However, an individual's age - the accumulated years – is relevant in other mechanisms in that the passage of time is associated with changes in a Person's state.

This code in interpreted with this comment in the project:

> *A person's lifetime extends from birth to death. Birth and death are stochastic events. Every person has a probability of survival that decreases primarily with time (age). This is one of the essential mechanisms that accounts for the dynamics of healthcare systems.*

Person encounters illness

Illnesses occasionally disrupt that normal course of living. The concepts of illness, and in of wellbeing its antithesis, are at the root of most mechanisms that form the networks of themes describing and explaining healthcare from its various perspectives in the literature Figure 5.22. Encounters with illness are events that individually constitute another essential mechanism in the dynamics of healthcare systems.

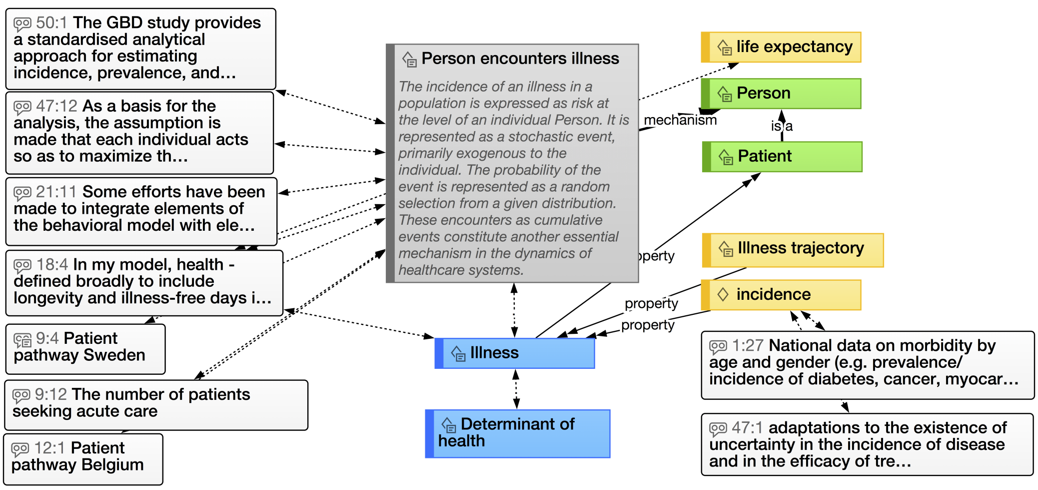


Figure 5.22: Illness encounters are central to the functioning of healthcare systems (Author's own).

As with birth and death, the occurrence of illness is referenced obliquely more often than directly in the literature. For instance, reports of health systems in transition include exemplars of patient pathways from which a precipitating illness event is inferred:

> "A woman in need of a hip replacement due to arthritis would take the following steps:.." (Anell *et al.*, 2012, quotation 9:4) See also (Gerkens and Merkur, 2010, quotation 12:1)

The occurrence of illness is also inferred in a discussion of the Human Capital Model alluding to *illness-free days*, previously referenced in Grossman (1972).

Episodes of illness are at the heart of most microsimulation models of clinical management strategy and health technology assessment (Rutter, 2017). The representation of illness episodes interprets contexts employed in that domain. It includes, in particular, the concept that, although the occurrence of an illness is a single event, the effects of an illness continue over time and follow a trajectory, as seen earlier in Figure 5.9.

Direct reference to the incidence and prevalence of diseases is most often observed in research such as the annual Global Burden of Disease study:

> "The GBD (Global Burden of Disease) study provides a standardized analytical approach for estimating incidence, prevalence, and YLDs by age, sex, cause, year, and location." (Vos *et al.*, 2017, Quotation 50:1)

The concept of illness itself, and its association with determinants of health and with trajectories, were discussed earlier.

The code describing the *incidence* of illness is summarized as follows:

> *The incidence of a particular illness in a population is expressed as a stochastic risk at the level of an individual Person. It is represented primarily as exogenous to the individual. Its probability of occurrence is represented as a random selection from a chosen or estimated distribution. An encounter with illness as one of a sequence of cumulative events constitutes an essential mechanism in the dynamics of healthcare systems.*

Person chooses on basis of affordability

When a person encounters an illness, she faces a choice of managing the effects of that illness independently, or of seeking professional help. The model represents this choice as an essential mechanism. A Person's decision to request care is a choice taken based on a personal threshold of discomfort or disability and on personal financial considerations of available income and insurance.

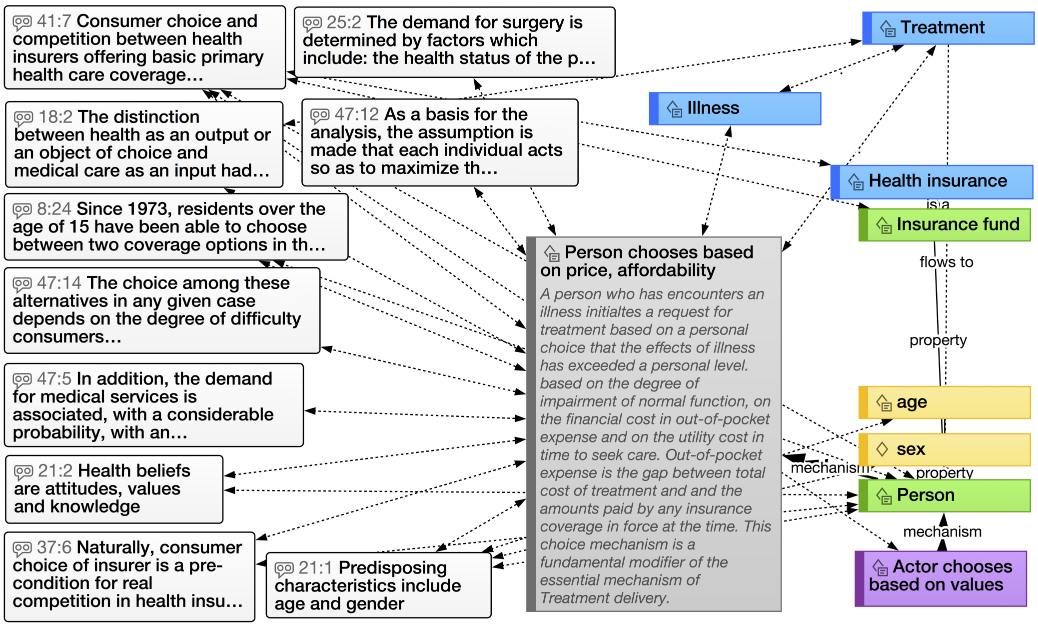


Figure 5.23: A choice to request care, taken under some conditions, initiates mechanisms of delivery and recovery (Author's own).

> "The choice among these alternatives in any given case depends on the degree of difficulty consumers have in making the choice unaided, and on the consequences of errors of judgment" (Arrow, 1963, Quotation 47:14)

These choices are based in part on beliefs about what the healthcare system itself can provide, but also on determining what will be required to pay for the care, as seen in Figure 5.23.

> "Healthcare beliefs or attitudes, values, and knowledge of people have about health and health services that might influence the subsequent perceptions of need and use of health services." (Andersen, 1995, Quotation 21:2)

Summarizing mechanisms associated with the occurrence of an illness episode:

> *A person who has encounters an illness initiates a request for treatment based on a personal choice that the effects of illness has exceeded a personal level. based on the degree of impairment of normal function, on the financial cost in out-of-pocket expense and on the utility cost in time to seek care. Out-of-pocket expense is the gap between total cost of treatment and the amounts paid by any insurance coverage in force at the time.*

As a theme, the basis of a Person's choice describes a third fundamental explanatory mechanism in healthcare systems. It concerns the availability of support external to the individual, and the processes for accessing that support. The choice mechanism explains some of the key phenomena observed in the healthcare systems of several countries.

Person reacts to treatment

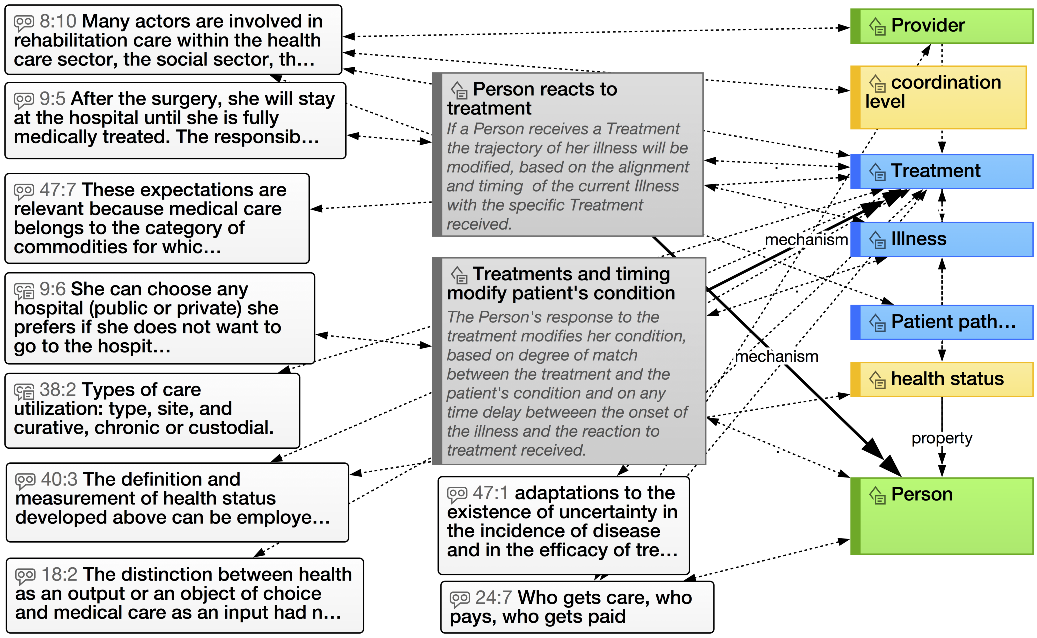


Figure 5.24: Reaction and response to treatment determines health status and may initiate a new cycle of requests for care (Author's own).

The theme illustrated in Figure 5.24, in which a Person responds to a received treatment, marks the relevance of the treatment chosen by a Provider to that Person's wellbeing during an episode of illness. A later section describes the mechanisms of illness and treatment. The mechanism of interest in this theme is the impact of the most recent treatment on overall well-being, and its role in an extended sequence in continuing care.

This theme is the domain of extensive research in clinical science and technology assessment, where the essential mechanism is the impact of treatment on wellbeing and on the trajectory of the illness in question (Hennessy *et al.*, 2015). Within the scope of the current research, this theme is treated as a simple mechanism. However, it includes possible variations in the impact of treatment that may result from variations in how the treatment is produced and delivered. The mechanism responsible for those variations is deferred to discussion of provision themes.

The comment on this theme in the codebook reads:

> *If and when a Person receives a Treatment, the trajectory of her illness is modified, based on the alignment and timing of the current Illness with the specific Treatment received.*

5.4.2 Basic themes associated with Providers

Figure 5.25 captures mechanisms associated with various types of actors and roles in reacting to requests and providing care. The actors follow a sequence of steps, usually connecting their mechanisms as bundles and in succession to meet the needs of the patient.

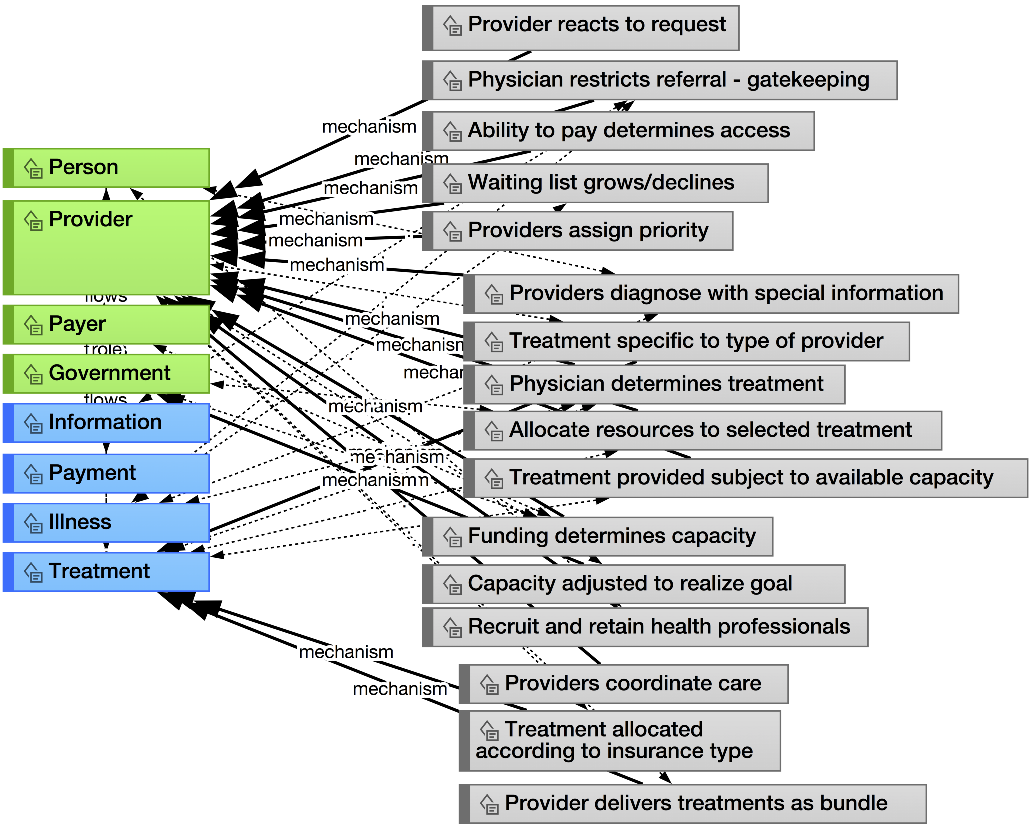


Figure 5.25: The second set of basic themes, mechanisms, attributes and abstractions co-occur with the Provider actor (Author's own).

The principal actors in this theme are providers of various types. As with the usage of Person in the previous section, the term *Provider* is applied here to indicate a concept that captures important generalized properties and mechanisms of the people and organizations that provide treatment and care. Those features and their heterogeneity were discussed earlier.

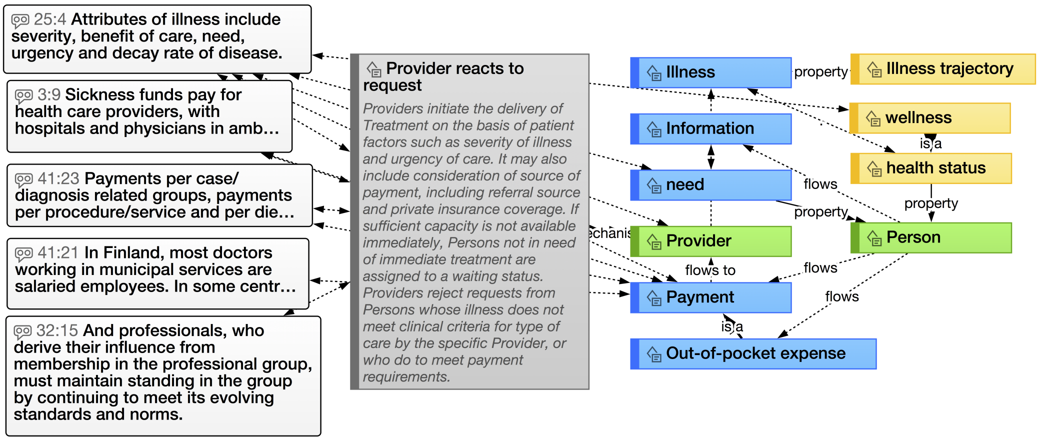


Figure 5.26: The first stage in providing treatment is acceptance by a Provider of the request for care (Author's own).

Provider reacts to request

This theme is a counterpart to the Person's request for care in the previous subsection. It represents an initial reaction and choice on the part of a Provider to accept and respond to the request on the basis of some criteria, or to reject it.

> "In Sweden, a woman in need of a hip replacement would typically take the following steps: The first visit would be with the primary care provider where she has chosen to be registered. According to the care guarantee, she should access a primary care physician within seven days but typically she will get an appointment within one or two days." (Anell *et al.*, 2012, Quotation 9:4)

If accepted, the request, subject to clinical criteria, is assigned a priority and placed in a queue. Highest priority requests receive the most immediate response.

> "Prioritisation policies aim to reduce such systematic disparities. There are different criteria, most of them clinical, which may be used to prioritise patients: severity of condition, expected benefit, need, urgency, the decay rate of the disease, the time already spent on the list." (Siciliani *et al.*, 2013, Quotation 25:4)

Other quotations in Figure 5.26 point to the relevance of sources of payment to the choice to respond positively to a request. The choice is based on a multiple values, including standards of professional practice:

> "…professionals, who derive their influence from membership in the professional group, must maintain standing in the group by con-

tinuing to meet its evolving standards and norms." (Tuohy, 1999b, Quotation 32:15)

The comment on this *reacts to request* code reads:

> *Providers initiate the delivery of Treatment on the basis of patient factors such as severity of illness and urgency of care. It may also include consideration a source of payment, including referral source and private insurance coverage. If sufficient capacity is not available immediately, Persons not in need of immediate treatment are assigned to a waiting status. Providers reject requests from Persons whose illness does not meet clinical criteria for a type of care by the specific Provider, or who do to meet payment requirements.*

Gatekeeping

Gatekeeping is an mechanism adopted in many countries to influence access to more specialized services, coded here as:

> *Where gatekeeping exists by regulation, requests to specialist physicians are restricted to primary care physicians.*

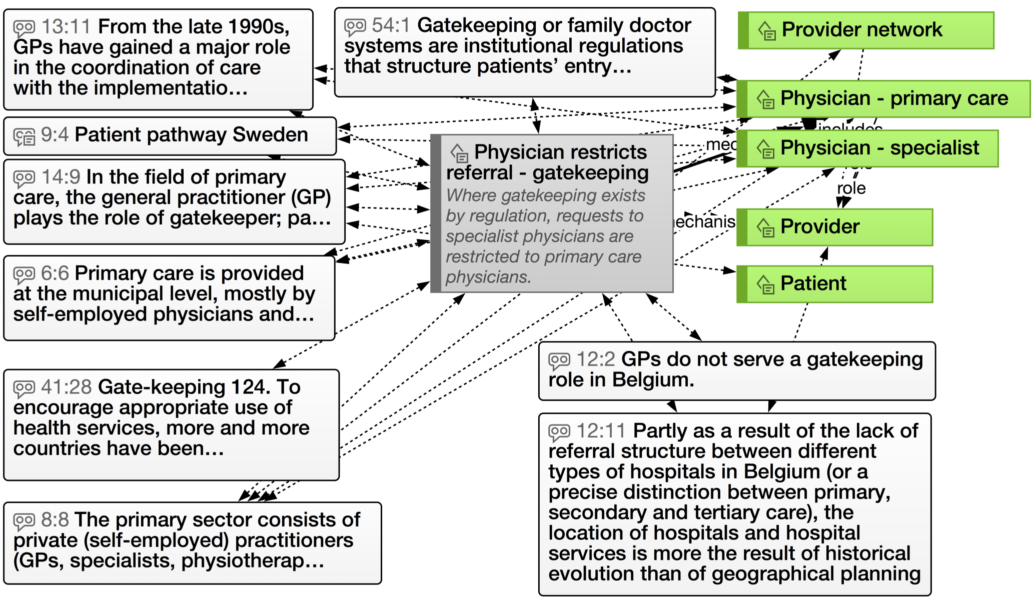


Figure 5.27: Gatekeeping limits access to speciality services in many but not all jurisdictions (Author's own).

Provision of care has evolved professionally over time. Many low acuity illnesses are treated entirely within the scope of practice of Primary Care

Physicians, but more complex conditions are managed by Specialist Physicians. Some jurisdictions restrict access to these specialists by requiring that the access be on the direction and recommendation of a Primary Care Physician. This constraint limits the overall delivery and utilization of provider services, but also imposes obligations of added coordination and communication among Providers. Through this exchange of communications and alignment of treatments, Providers are linked to one another as networks.

> "In the field of primary care, the general practitioner (GP) plays the role of gatekeeper; patients need a referral from a GP before they can go to a medical specialist. Traditionally the GP used to work alone, but since the 1970s group practices have become popular. In the meantime, primary care centres emerged where GP care was combined with other primary care provision, such as district workers and physiotherapists" (Paris *et al.*, 2010, Quotation 14:9)

The requirement is not universal, however, as evidenced by this extracted text:

> "GPs do not serve a gatekeeping role in Belgium. Patients have free choice concerning the first physician to contact, can change physicians at any time, get a second opinion, or even consult several physicians at a time. Moreover, they can directly access specialists or enter hospitals. The free choice of physician is an important right granted to patients." (Gerkens and Merkur, 2010, Quotation 12:2)

And consequences have been observed for this lack of referral:

> "Partly as a result of the lack of referral structure between different types of hospitals in Belgium (or a precise distinction between primary, secondary and tertiary care), the location of hospitals and hospital services is more the result of historical evolution than of geographical planning." (Gerkens and Merkur, 2010, Quotation 12:11)

Diagnosis of illness

Special skills are required in determining the types and therefore the costs of treatments required to meet patients' needs. They exercise substantial influence in allocation of resources towards treatment, and in setting market prices where appropriate.

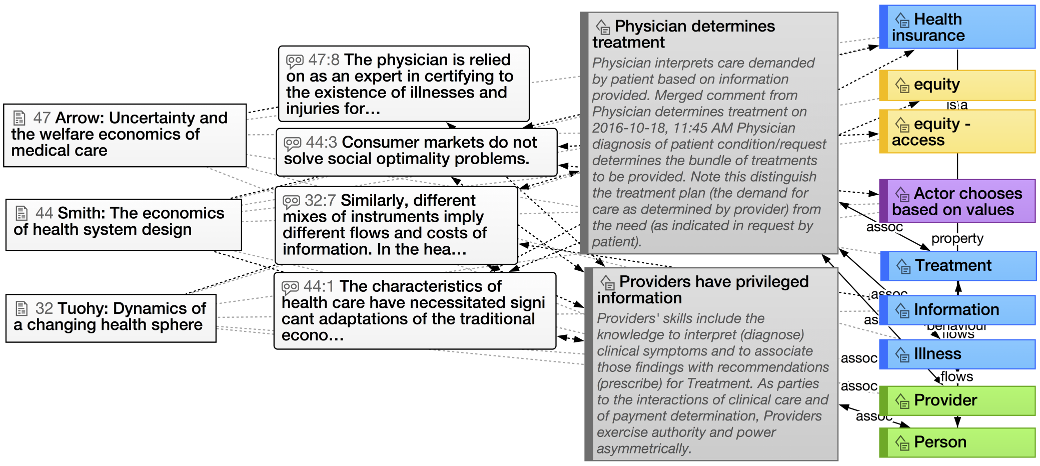


Figure 5.28: Physician use privileged information to diagnose illness (Author's own).

> "[D]ifferent mixes of instruments imply different flows and costs of information. In the health care arena the information gap between patient and provider traditionally has underlain the establishment of agency relationships whereby patients delegate decision-making authority to providers." (Tuohy, 1999b, Quotation 32:7)

The relationships between Providers (and physicians in particular) on the one hand, and Persons and others who pay on the other hand, are asymmetric:

> "The physician is relied on as an expert in certifying to the existence of illnesses and injuries for various legal and other purposes. It is socially expected that his concern for the correct conveying of information will, when appropriate, outweigh his desire to please his customers." (Arrow, 1963, Quotation 47:8)

The code for *diagnosis* is described in these terms in Figure 5.28:

> *Providers' skills include the knowledge to interpret (diagnose) clinical symptoms and to associate those findings with recommendations (prescribe) for Treatment. As parties to the interactions of clinical care and of payment determination, Providers exercise authority and power asymmetrically.*

Coordination of treatments

As a complement both to the gatekeeping theme and the specialization of physician services, the coordination theme describes a mechanism that addresses the alignment of treatments among multiple Providers (Figure 5.29).

> "From the late 1990s, GPs have gained a major role in the co-ordination of care with the implementation of a semi-gatekeeping system that provides incentives to people to visit their GP prior to consulting a specialist. " (Chevreul *et al.*, 2010, Quotation 13:11)

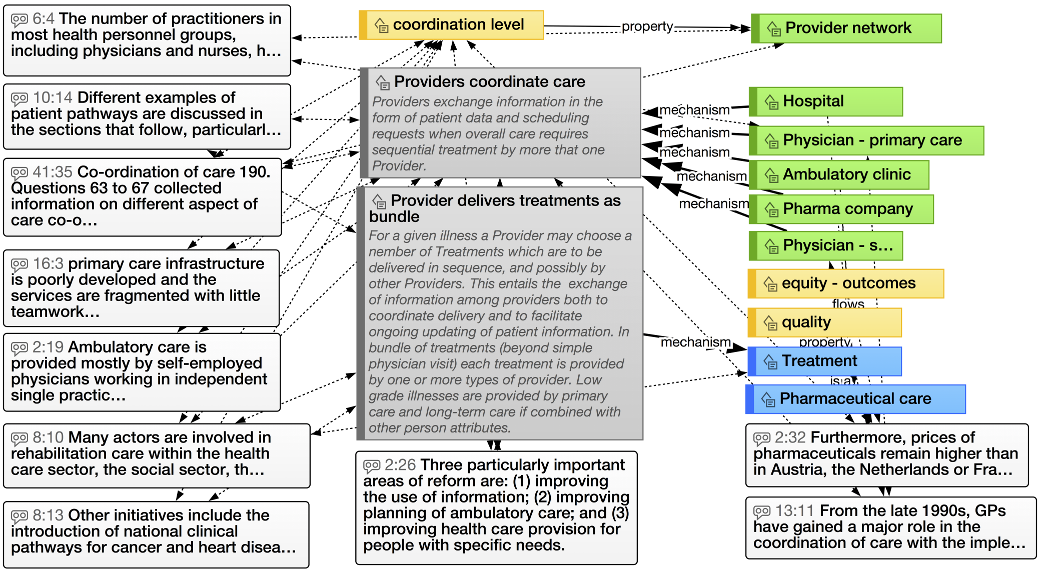


Figure 5.29: Coordination among providers influences the delivery of bundled and sequential treatments (Author's own).

A survey of 29 OECD countries asked contributors to assess their country's performance in respect of a variety of policies and practices, included those supporting communication and alignment among Providers, and produced this extract on coordination:

> "Questions 63 to 67 collected information on different aspect of care co-ordination: the use of disease or case management programmes, the use of electronic health records and co-ordination between the acute and rehabilitative/long-term sectors care." (Paris *et al.*, 2010, Quotation 37:20)

Figure 5.29 shows two themes (grey panels) related to coordination among Providers. The first relates to the *mechanisms of information exchange* that create and maintain communications that coordinate treatment by sharing and aligning information efficiently and without waste. The second relates to *bundling separate treatments together*, mainly through consults and referrals among Providers who add complementary specialty services such as diagnostics, therapeutics and rehabilitation to the underlying treatment plans.

5.4.3 Basic themes associated with payment by Payers

Figure 5.30 captures mechanisms associated with the various mechanisms associated with Payers in compensating or reimbursing Providers for the Treatments provided to Persons. The most frequent mechanisms relate to the ongoing flow of funding, but the themes also include mechanisms that adjust the pricing and regulation of services.

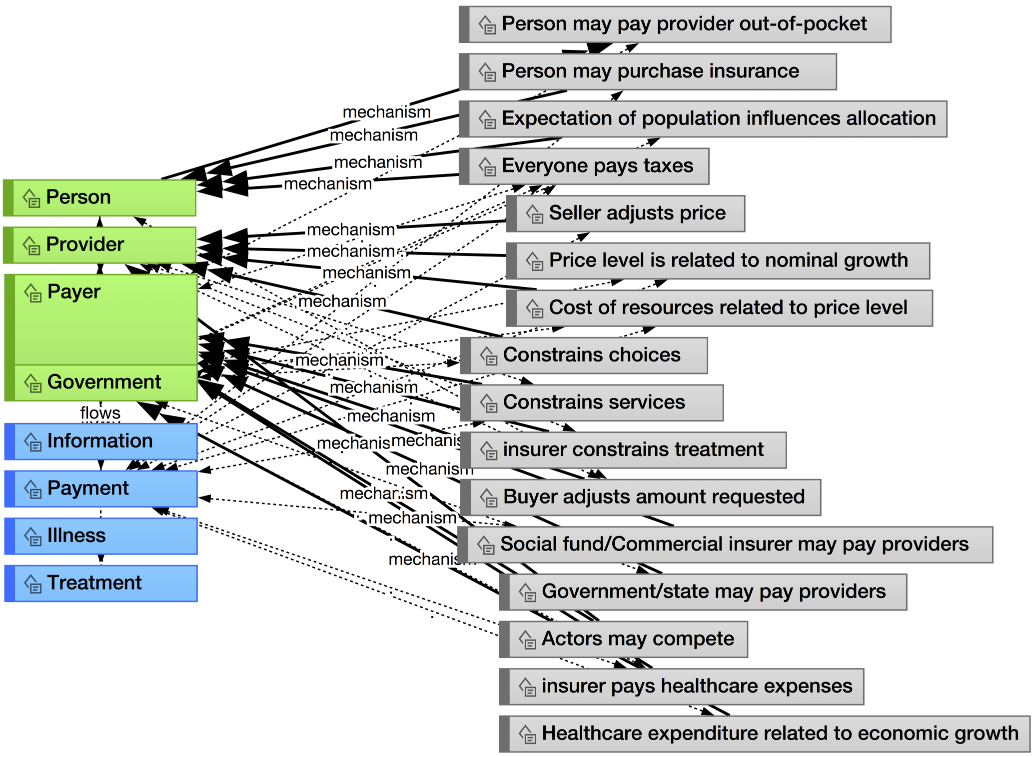


Figure 5.30: The third set of basic themes, mechanisms, attributes and abstractions co-occur with Payer actors (Author's own).

Providers and Persons participate in these themes along with Payers, a generic type of actor that includes government, and organizations, both corporatist and private, dedicated to the provision of health insurance.

The participants in this Payment theme include Persons and Provider actors, both of which have been specified before. The person actor adds *pay for Insurance* as another mechanism to the specification. The provider adds two mechanisms: *report mechanism* (to initiate funding) and *update pricing* (as a participant in a competitive market).

Payer flow funds in several forms

Paris *et al.* (2010) provides extensive documentation for the provision of health insurance across most OECD countries. Quotations from this document are indexed in Figure 5.31.

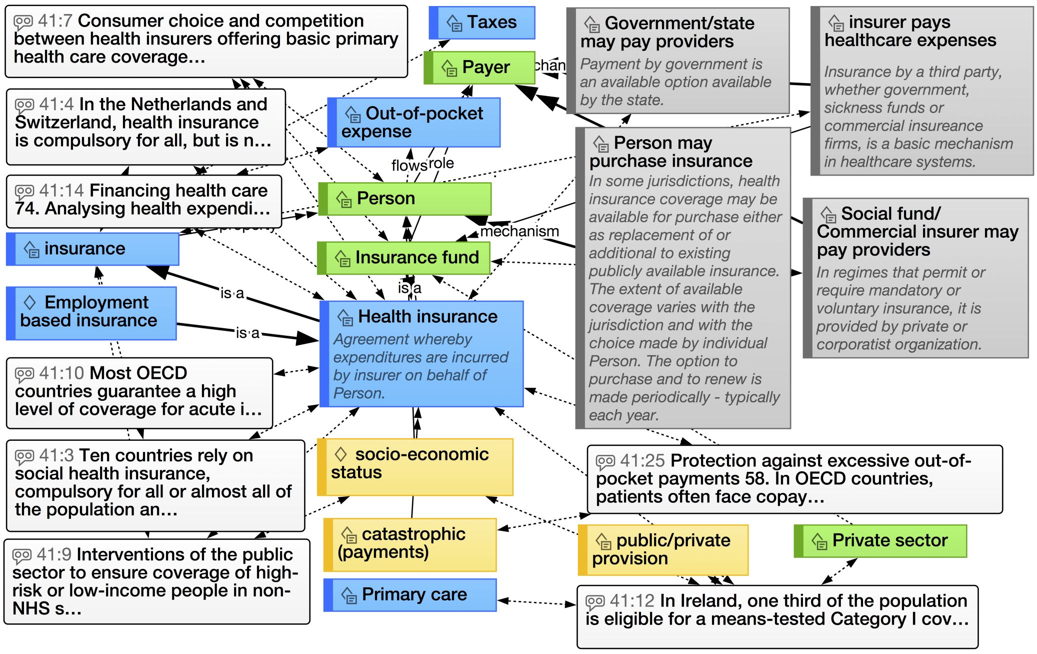


Figure 5.31: Health insurance is a frequent recurring concept in the literature (Author's own).

Four basic themes describe mechanisms that result in payments to providers – *taxes*, *social or statutory insurance*, *premium payments* and *out-of-pocket payments*. As a general principle, funds flow to Providers from an insuring entity; at times shortfalls are made up through out-of-pocket payments by individual Persons. The insuring entities vary among countries. In some cases the cost of care is supported directly by governments, while in others, state funding augments the payments provided through various forms of social insurance, linked either to professions, as in France, for example, or to employment in Germany and the Netherlands. Commercial insurance firms also provide insurance in return for premium payments. Where health insurance is provided primarily by nongovernment agencies, the government will often insert special funding for socially disadvantaged Persons who would otherwise not afford coverage.

Government funding

Governments participate in healthcare through a number of mechanisms (see Figure 5.32). In England, for instance, the government has been responsible for funding and delivery of healthcare services since the establishment of the NHS:

> "The stated objective of the introduction of the NHS was to create equitable access to health care by making health services free at the point of delivery. " (Boyle, 2011, Quotation 10:2)

The channels through which funding flows at state level vary among jurisdictions. Some assemble contributions from employment and other sources as common pools from which funding is distributed. Others fund health services directly from the tax system:

> "The Irish health care system remains predominantly tax funded. In 2006, 78.3% of total health expenditure (both public and private) was raised from taxation, including pay-related social insurance (PRSI) and other sources of government income, such as excise duties." (McDaid *et al.*, 2009, Quotation 16:23)

Actions of government take account of the expectations of the population; this consideration influences choices leading to allocation of funds between healthcare and other socially or economically desirable purposes. Notably, governments at times delegate funding and governance roles to lower-level authorities often regionally based.

> "In very broad terms, state actors function within systems in which those in command ultimately are dependent upon political support and therefore seek to accommodate a range of interests and opinions sufficient to maintain a coalition of support." (Tuohy, 1999b, Quotation 32:5)

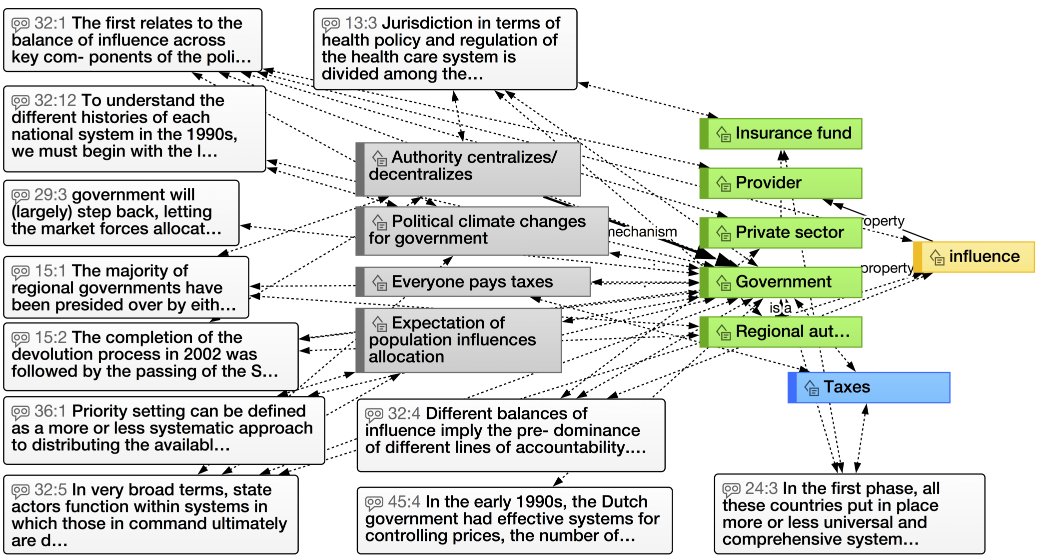


Figure 5.32: Government participates in the payment exchange (Author's own).

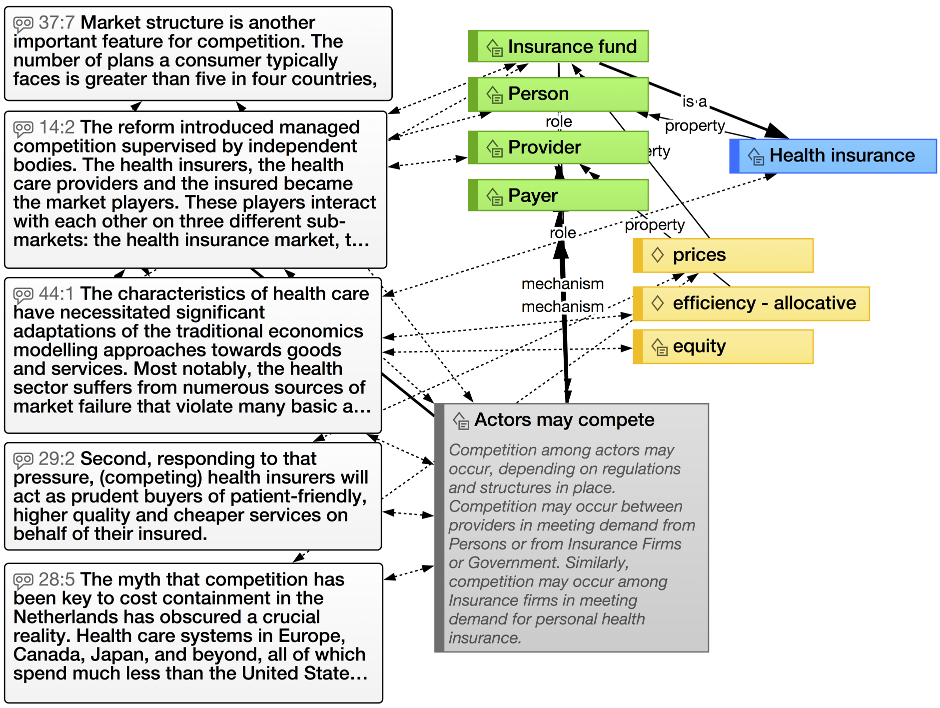


Figure 5.33: Market mechanisms have been introduced to contain costs (Author's own).

Markets and competition

The *actors may compete* theme in Figure 5.33 represents a market in which goods – treatments – are traded for revenues. Depending on the configuration of institutions, the market may be monopolistic, monopolistic, or possibly openly competitive. A number of authors have observed that the healthcare market regardless of its configuration is prone to failure. For example:

> "The characteristics of health care have necessitated significant adaptations of the traditional economics modelling approaches towards goods and services. Most notably, the health sector suffers from numerous sources of market failure that violate many basic assumptions inherent in traditional economic models." (Smith and Yip, 2016, Quotation 44:1)

Some countries have implemented competitive markets in various forms, and with varying results:

> "The myth that competition has been key to cost containment in the Netherlands has obscured a crucial reality. Health care systems in Europe, Canada, Japan, and beyond, all of which spend much less than the United States on medical services, rely on regulation of prices, coordinated payment, budgets, and in some cases limits

on selected expensive medical technologies, to contain health care spending." (Okma *et al.*, 2011, Quotation 28:5)

Regardless of the success or otherwise of competitive markets, the model allows for the representation of competition. The theme is defined as follows in the codebook:

> *Competition among actors may occur, depending on regulations and structures in place. Competition may occur between providers in meeting demand from Persons or from Insurance Firms or Government. Similarly, competition may occur among Insurance firms in meeting demand for personal health insurance.*

5.5 Mechanisms as organizing themes

Figure 5.34: Basic mechanisms are grouped by common common purpose and participation into colour coded organizing themes (Author's own).

The previous sections identify and catalogue a range of mechanisms as basic themes that emerge in the analysis of texts. In those sections, these basic themes are provisionally associated with the basic actors, Persons, Providers and Payers. In this phase of the analysis, the basic themes are grouped as *organizing themes* on the basis of common purpose and participants. Three groups emerge at this intermediate level of thematic analysis. To emphasize their essential roles in the representation of healthcare systems in Figure 5.34, each is assigned a colour code that is continued in the later versions of the model.

- *Life Course* (pink) captures the mechanisms of individual people when they encounter illness during the course of their lives; this is the domain of epidemiology.
- *Provision Network* (blue) captures the mechanisms of clinical people and organizations who provide care; this is the domain of operations research.
- *Payments Exchange* (green) captures funds are gathered and transferred to providers in compensation for services provided; this is the domain of health economics.

5.5.1 Organizing themes of Life Course

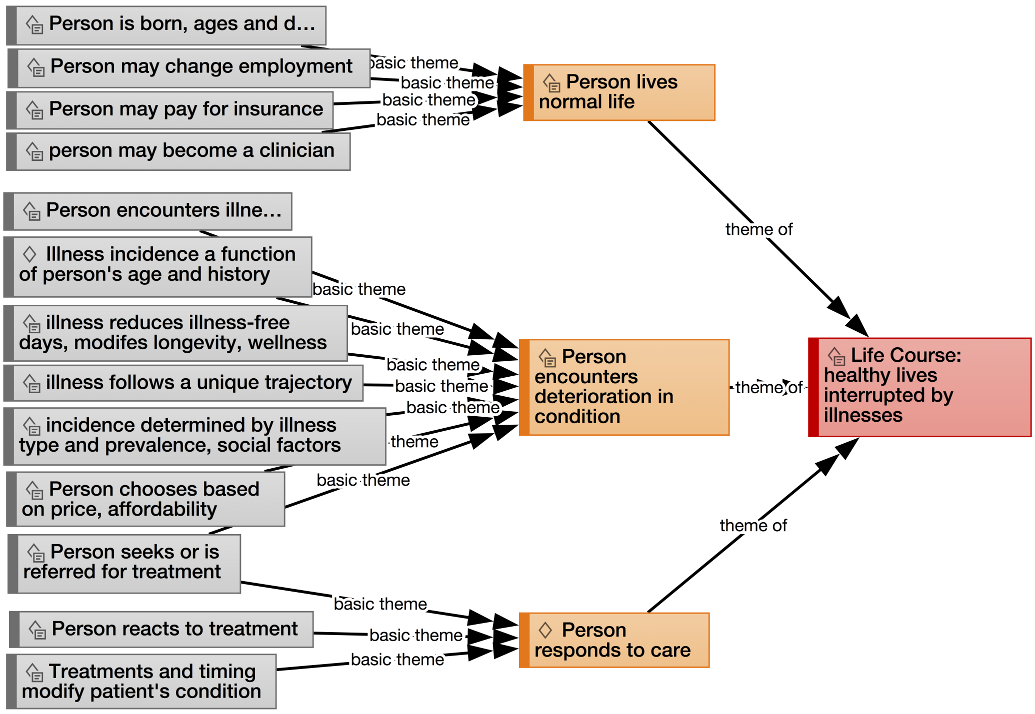


Figure 5.35: Life Course global theme

The Life Course global theme (Figure 5.35) condenses the mechanisms (subsection 5.4.1) that mark the life time journeys of individuals in the population. The basic themes that emerge from the datasets in the literature make sense in three organizing groups.

Person lives normal life

The backdrop to Life Course theme is the normal life of a Person, pursuing activities of daily living with independence. This is consistent with the WHO definition of health as more than the absence of illness. The life course of every individual is initiated by birth and concluded by death, an essential mechanism that produces the underlying demographic dynamics in the population.

Three other mechanisms during a Person's life course may relevant to healthcare in general but marginal to the primary demographic mechanism. A change in a Person's employment may have implications for support during times of illness. There are similar implications to a choice to purchase personal insurance. And for reasons unrelated to personal health, but with implications for the provision of care, the career choices of some Persons have implications for the availability of qualified clinical professionals.

Person encounters deterioation in condition

Health has been defined as "...not merely the absence of disease or infirmity" (World Health Organization, 1946), but the impact of illness in the lives of individuals is a fundamental mechanism in explaining what happens in healthcare systems. The second organizing theme gathers together a number of mechanisms that produce connections to other domains of the whole healthcare system.

An initial (or continuing) encounter with illness impairs wellness, reducing accumulated illness free days, and may shorten a Person's longevity. An encounter, when it happens, is precipitated in part by the combined influence of a person's age and history. The reduction in wellness follows a trajectory characteristic of the particular type of illness, and may lead to the Person considering a request for professional help. The choice to do so is based on multiple considerations, balancing the therapeutic benefits of treatment with any economic or disruptive costs associated with the processes of obtaining and responding to the care.

Person responds to care

The effects on wellness and dependence follow individual trajectories that are associated with particular illnesses. Persons who receive treatment suited to a current illness react positively to that treatment if it is delivered in time and in a manner that is appropriate to the Person's condition. This recognizes observed variations and delays in the treatments provided in the real world, and incorporates representative mechanisms in the model.

Indicators of interest in the LifeCourse theme

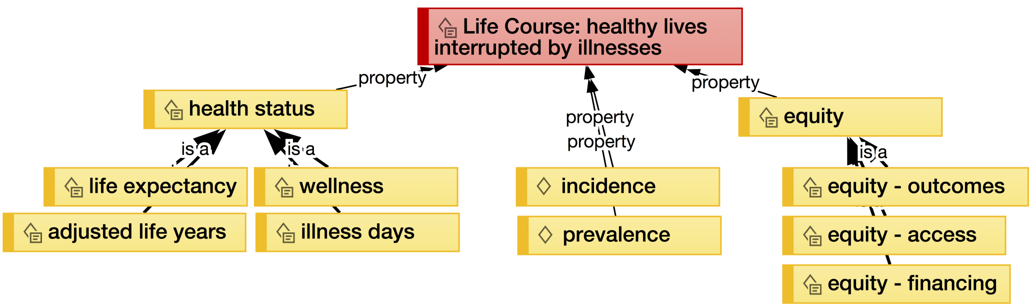


Figure 5.36: The indicators of interest in the Life Course theme are aggregates of the variables at the level of the individual Person

The earlier discussion of the top level systems referred to the aggregate variables that may be observed at that level. These originate with the individual Persons who are associated with this global system. The input and output are depicted in Figure 5.36. Many of these themes reference *variables of interest* in assessing the performance of real world healthcare systems, and in developing policies that might improve that performance, as evidenced in the literature review earlier in this dissertation. In practice, the choice of variables for experimental and implementation purposes is limited to those *accessible and observable* in the real world. It is worth noting that additional conceptual constructs, such as wellness and illness-free days in an artificial, may be included in synthetic models, even when they are empirically inaccessible in the real world.

5.5.2 Organizing themes in Provision Network

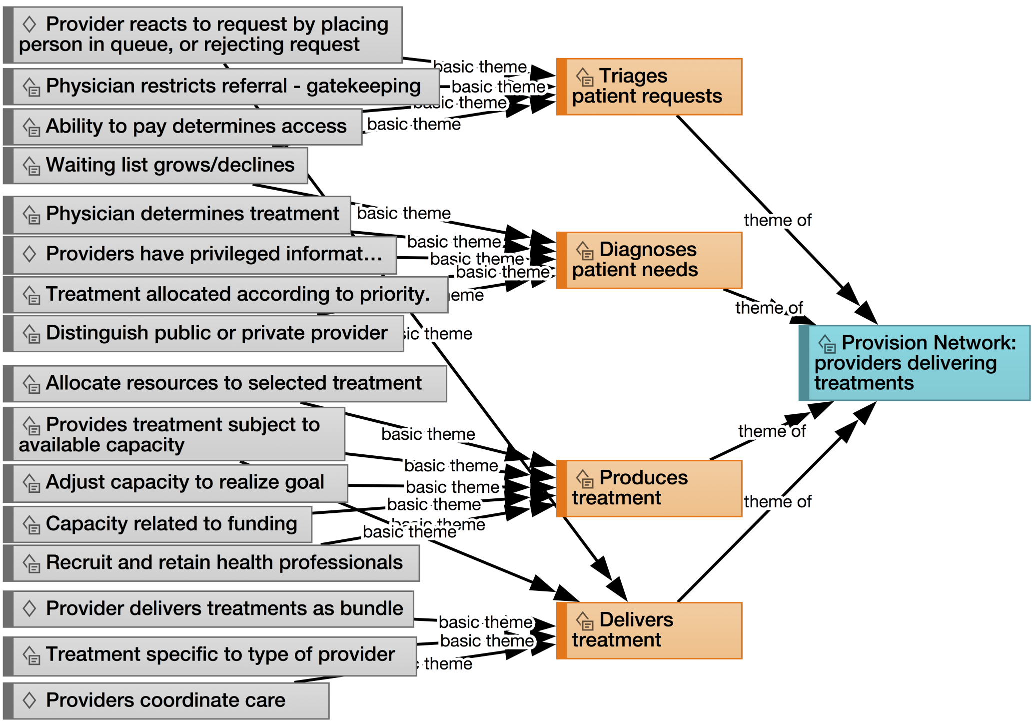


Figure 5.37: Providers accept requests, diagnose and deliver treatments (Author's own).

The mechanisms, actors and entities gathered in this theme (Figure 5.37) indicate how Providers of care react and respond through a sequence of four mechanisms (see subsection 5.5.2) to a request for care. A provider steps through assessment for appropriateness, diagnosis of the disease processes underlying the presenting illness, mustering and processing of resources to produce an appropriate treatment, and then delivering that treatment to the person who requested it.

Triages patient reequests

A Provider react to requests in various ways and under various conditions. In many jurisdictions, for example, hospitals and specialist physicians will not accept direct requests for care without the prior acceptance of a primary care physician[8]. Providers will usually accept requests for care only with the expectation of eventual compensation for their services, although moral and professional standards may prevail in some circumstances. Subject to these considerations, a provider reacts to a request for care immediately if urgency requires, or by deferring the request, maintaining a list of those waiting until resources become available.

Diagnoses patient needs

While requests for care are couched in terms of the requesting person's perceived wellness - or illness - the choice of treatment rests with the provider who has access to sources of information not readily available beyond the community of providers. This is relevant in that subjective variation in the selection of the treatment by the provider may have consequences for its cost, and for its effect on the trajectory of the person's illness, but would be difficult and costly to assess objectively.

Produces treatment

Having determined the course of treatment to be provided, the Provider allocates resources - professional and facility time, clinical and ancillary supplies - from within available capacity which is determined and constrained by funding. Providers reallocate funding periodically to adjust capacity in meeting requests. This includes providing for adequate human resource capacity especially in regulated professional groups such as nursing and medicine.

Delivers treatment

The final stage in treatment provision is delivery of the produced resources to the patient. Since most courses of treatment involve more than one provider, a treatment step normally includes at least one more step that involves the same or another provider. Delivery of any one treatment therefore includes another iteration of the request for care sequence, as a prescription for medication, as a follow-up consultation or as a referral to another provider. It is in this respect that Providers form a network of communication and collaboration. The outcome of the overall bundle of treatments provided to a given person as a patient depends in part on the effectiveness of that coordinating network.

[8]This includes physicians providing emergency services.

Indicators of interest in Provision Network

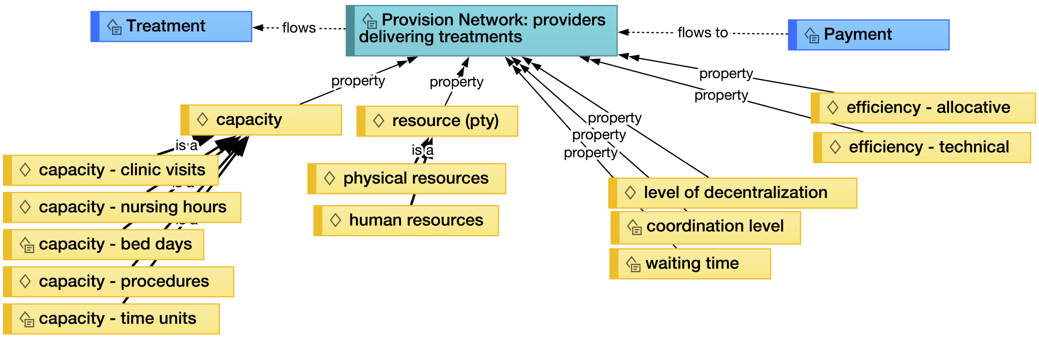


Figure 5.38: The indicators of interest in the Provision Network theme are aggregates of the variables and flows (Author's own).

The earlier discussion of the top level systems referred to the aggregate variables that may be observed at that level. These originate with the individual Persons who are associated with this global system. Figure 5.38, for instance, represents properties of Providers that change with the inflow of resources (Payment) and are used in the production of treatments as outputs.

Once again, although many of these represent variables that may be accessible and observable in the real world. The inclusion in an artificial, synthetic model can also represent measures such as efficiency and levels of coordination across the network that are empirically inaccessible in the real world.

5.5.3 Organizing themes in Payment Exchange

In the Payment Exchange theme (subsection 5.4.3), insurers, government and individual people transfer funds to Providers in exchange for services provided. The transfers originate and flow in various channels. Amounts of funding are calculated in diverse ways, and depend on regulatory and industry rules in place from time to time. All jurisdictions include some form of indemnity against and risk sharing of the costs of healthcare, but the specific structures vary greatly among them, and are at times the objects of healthcare reform. Under some conditions, market processes determine prices of clinical services and of risk sharing.

Various payers pay various providers in various ways

Figure 5.40 depicts the diversity of payers who flow funds to providers, and the variety of ways in which those funds flow. Persons at times pay out-of-pocket for care, frequently pay premiums for health insurance (either personally or through employers) and almost always contribute to state revenues through various taxes. Insurers, either commercial or statutorily constituted, pay for

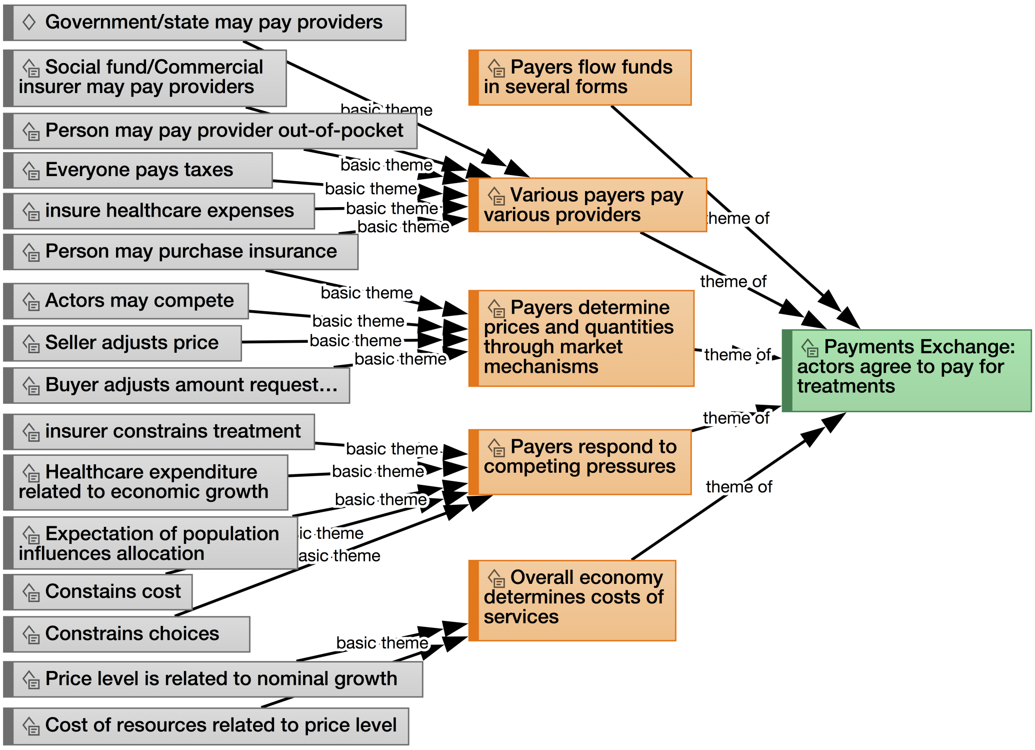


Figure 5.39: People, government, insurers transfer funds to Providers in a Payment Exchange (Author's own).

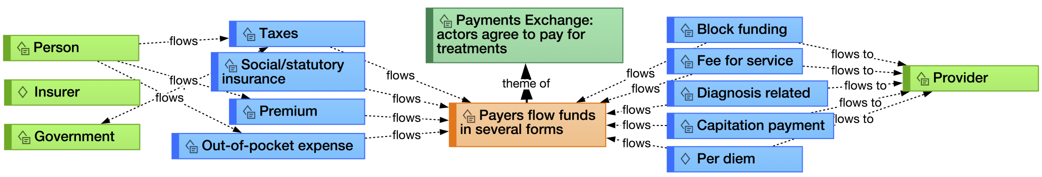


Figure 5.40: Funds flow in several channels and forms (Author's own).

services on behalf of policy holders under agreed upon conditions. And in many jurisdictions, government participate actively in payment for healthcare services.

Government, at various levels of decentralization or regionalization is primarily a regulator that constrains the behaviors of other participants but is constrained for its part by the collective sanction of the population at election time. Insurance firms sell contracts to individuals directly or indirectly through employers. The price is set and updated periodically based on prices paid to providers and on historical revenues and market share. Payments flow in several channels to Providers. In Beveridge type national systems (such as the NHS in England, the provincial governments in Canada, or local government in Sweden) funds flow directly from tax revenue gathered by the government to Providers. In jurisdictions where the healthcare system is based on the Bismarck model with statutory health insurance (SHI), the funds flow from sickness funds that are associated with trades and professions (as in France) or with geographic regions (as in the Netherlands). When costs of treatment exceed the funding provided by government or insurers, or fall outside the services covered, patients pay providers directly *out-of-pocket*.

Payers respond to market pressures

Where competitive markets exist, prices are agreed on an annual basis between providers and insurers (or government if relevant), and between insurers and individual paying for insurance (either directly or through employer plans).

Overall economy determines costs

Prices used in calculating and paying for services are determined by primarily by labour costs which in turn are strongly influenced by overall wage levels in the broader economy.

Market mechanisms describe how producers and consumers adjust the volume and price at which goods are exchanged. Many economic models assume equilibrium; the intermediate choices, reactions and responses are not observed. In this systems model, choices are made on the basis of gaps between target and actual values of certain attributes, often involving thresholds and transitions that are triggered over time. For this reason, the model does not assume that markets are cleared. Rather, the assumption is actors periodically assess performance and make choices on the basis of actions in the prior period, with may (or may not) clear markets.

> "The characteristics of health care have necessitated significant adaptations of the traditional economics modelling approaches towards goods and services. Most notably, the health sector suffers from numerous sources of market failure that violate many basic assumptions inherent in traditional economic models. To cite just a few: profound asymmetries of information between providers of health services and their patients; major economies of scope and scale, most obviously but not solely in the hospital sector, that inhibit the development of conventional competitive provider markets; existence of explicit or implicit insurance markets that are replete with problems of adverse selection and moral hazard; and countless externalities, especially in the form of infectious diseases (Smith, 2000). These market failures mean major policy interventions are needed for the health sector to achieve the social goals of efficiency and equity." (Smith and Yip, 2016, Quotation 44:1)

> "Many European countries have experimented with (quasi-) market-oriented reforms, which has made their regulatory challenge considerably more complex as governments now also need to monitor the competitive strategies and rent-seeking behaviour of third-party payers and health-care providers (both public and private). However, the re-distributive and stabilization function of governments has not diminished in importance." (Helderman *et al.*, 2005, Quotation 35:2)

Indicators of interest in the Payment Exchange

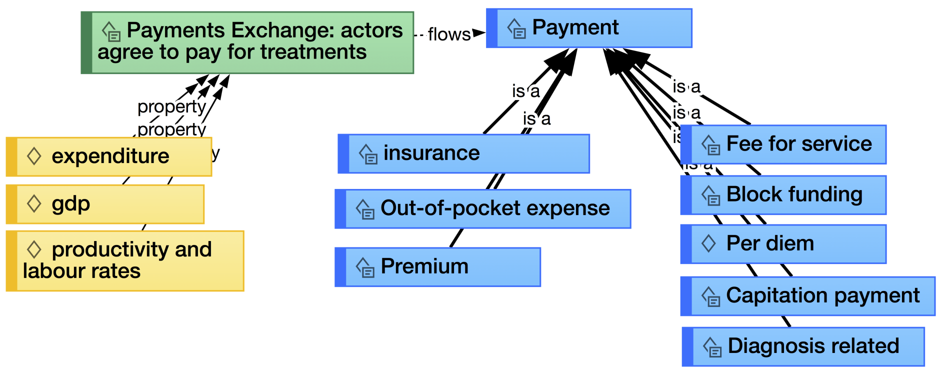


Figure 5.41: The indicators of interest in the Payments Exchange theme include flows of payments and economic indicators (Author's own).

Overall expenditure on healthcare emerges as the major indicator of interest in the Payment Exchange system. Indicators of payment flows fall into two groups – payments that flow to Providers in various forms, and the payments that originate with various actors. Inputs of interest include changes in domestic product and associated changes in overall price levels.

5.6 Change in the themes model

Figure 5.42 depicts how the SMoH-t version of the model represents the inherent dynamic nature of healthcare in the real world. Exogenously, the incidence and prevalence of illnesses in the population change with natural variations in birth rates, with decreasing or increasing propensity to illness and with limitations to activities of daily living associated with aging of population cohorts. Clinical, pharmaceutical and technological advances modify rates of cure, remission and recovery. Inflation and economic growth increase prices and labour costs.

The Change global theme is distinct in that it describes the behaviours in terms of *events* - changes in state that evoke reactions and responses in

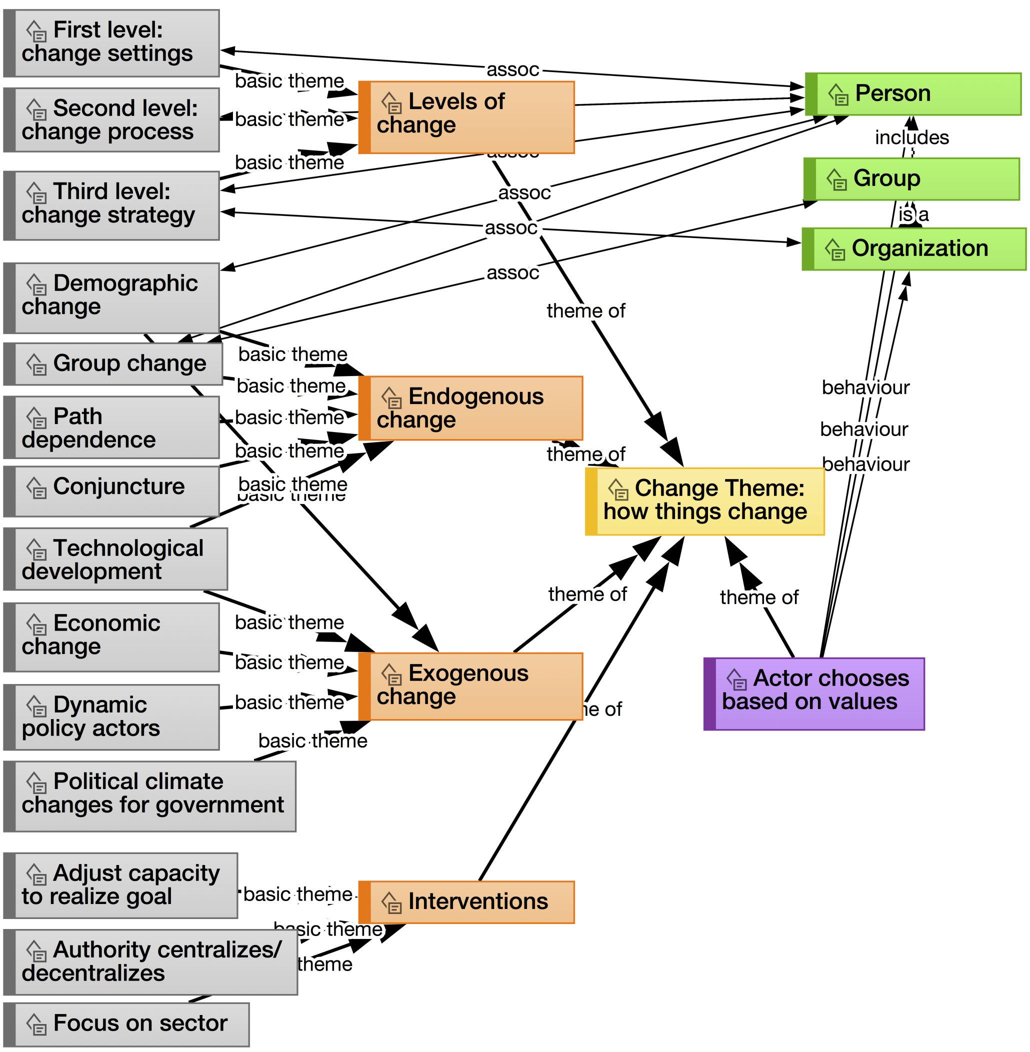


Figure 5.42: Changes theme explains why events happen (Author's own).

other elements of the system. Change theory is expressed in terms of level and locus. The levels distinguish the scale of reaction and response, while the locus distinguishes between those changes that penetrate the boundary of the system and those that occur within, either from the intentional responses of system actors, or that emerge from the adaptive behaviours of member systems as they react to the other systems that share their context. The theme also includes some interventions as exemplars of reforms, but this is illustrative only, and is extended in the discussion relating to validation and acceptance.

5.6.1 Choice as a change mechanism

The *choice* mechanism is a recurrent theme in the thematic systems model, appearing as explicitly as a term in some quotations, and semantically in others as synonymous words or phrases. When associated with various types of actors, *choice* is an mechanism of selecting one option from among many,

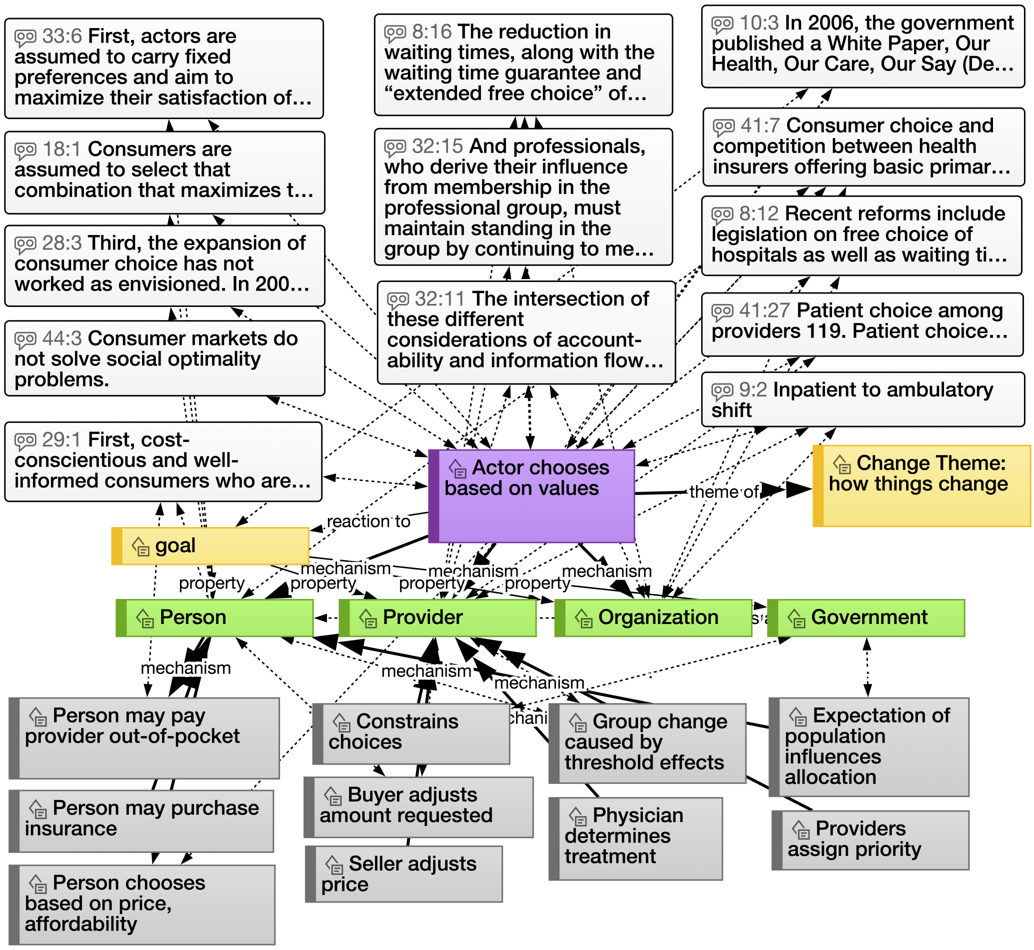


Figure 5.43: Choice as a basic theme is grounded in quotations and occurs variously in many basic themes (Author's own).

based on assessment of the costs and benefits of each one. This has many layers, in psychology and in game theory, for instance. In the model the choice mechanisms are confined to balance of beliefs, with constant desire and intention. Each of these references a goal. As Figure 5.43 illustrates, it is grounded densely in the quotations, and is associated in the interior of a number of more complex themes. The literature describes a person's freedom to choose among hospitals in Denmark, for example:

> "Recent reforms include legislation on free choice of hospitals" (Olejaz *et al.*, 2012, Quotation 8:12).

And at a personal level

> "Consumers are assumed to select that combination that maximizes their utility function subject to an income or resource constraint: namely, outlays on goods and services cannot exceed income." (Grossman, 2000, Quotation 18:1)

As a basic theme, *Actor chooses* generalizes mechanisms involving various types of Actors – Persons, Providers, Government and Organization entities – and crucially involves a selection that is based on the values of state variables specified as a respective Actor's *Goal*. In reaction to the occurrence of an illness, the Person exercises a choice to seek care under some conditions, as coded to Quotation 18:1 above, to pay out-of-pocket, or to purchase health insurance. Physicians as Providers make choices as diagnose and as orders for treatment. Their choices may be influenced by prevailing opinion among peers, by, for instance, intentionally reducing variation in practice among peers:

> "And professionals, who derive their influence from membership in the professional group, must maintain standing in the group by continuing to meet its evolving standards and norms." (Tuohy, 1999b, Quotation 32:15)

This text extract is reminiscent of the threshold mechanism advanced by Granovetter (1978) to explain group behaviour.

Governments as Organizational Actors choose on the basis of articulated goals that are weighted from time to time by the aggregated expectations of the Population.

5.6.2 Levels of change

This organizing theme reflects an account of change proposed by Hall (1993). Hall's thesis is that policy changes may be considered as functioning at one of three levels of a system. At the uppermost, third level, strategies guide the realization of the system's purpose and goals. Each strategy is implemented at an intermediate second, levels using chosen mechanisms that include resources and activities. The execution of the mechanisms occurs at the lowest, first level. Hall's account proposes that changes occur at any one of these levels, subject to their implementation by actors with the power to do so. Level one changes fall within the remit of actors responsible for the activities and resources they use, and are executed by changing volumes and rates; Hall refers to these as "instrument settings". Level two changes require changes of mechanisms – the instruments themselves. They require participation of a broader coalition of actors. At level three, changes to a strategy – the set of mechanisms intended to realize a goal – require substantial broader coalitions, and are more difficult to realized. (Ranci and Pavolini, 2015) use the levels of change construct in explaining how a number of countries addressed the growing problem of caring for older populations with approaches that differed based on institutional structures that limited the coalitions and activities available to resolve the pressures.

5.6.3 Endogenous change

Demographic changes dominate the dynamics of the model. The creation and removal of Persons and the occurrence of Illness represent birth, morbidity and mortality rates in the real world. It is assumed that these are endogenous, determined by events and actions within the overall context of the model.

Other phenomena, such as path dependence (and conjuncture, its dual) and processes of group change are represented in the model not as as themes created *de novo* in the analysis but as emerging from other mechanisms and themes.

5.6.4 Exogenous change

Three themes describe both endogenous and exogenous change mechanisms in the model.

Although changes in the population and in the incidence and prevalence of illness occur with the Life Course global theme, changes in the external environment, such as social or economic policies that modify the social determinants of health, can exogenously modify the endogenous changes described previously.

Technological change, of the sort that modifies the effectiveness or efficiency of treatment for example, is prominently exogenous to the working of the model, although it does allow that Providers engaging in diagnostic and therapeutic activities with a scientific intent may endogenously produce technological change as well.

Economic changes – shocks representing events such as the Great Recession of 2008 – and changes in the political and social landscape are also exogenous to the model. Substantial changes are at times attributable to the personal actions and influences of individual political actors.

5.6.5 Interventions

Finally, representing an open system, the model allows that change interventions produce results that, in keeping with the foundational epistemic purpose of the model, would be deduced as explanatory in the model and inferred to its target in the world as a test of strategy. The interventions in Figure 5.42 are exemplars and placeholders only.

5.7 SMoH-t: A system of themes

The patterns of actors, abstractions and flows describe and explain mechanisms first in low level themes, later in organizing and then global themes. Together they produce a top level model that contains within it explanations of how healthcare systems function as a whole system.

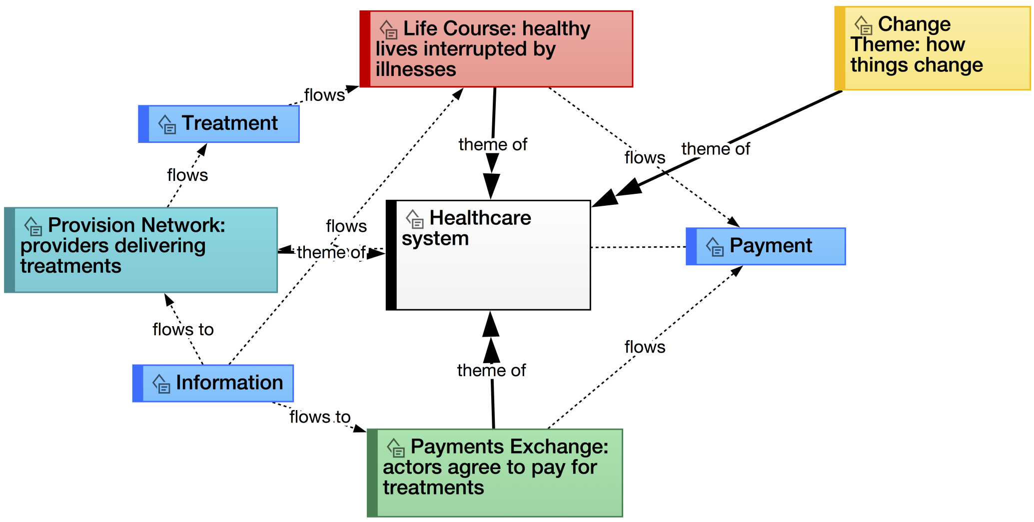


Figure 5.44: Top level of the themes version, SMoH-t, shows a system of three systems, connected by flows (Author's own).

The themes version of the Systems Model of Healthcare explains healthcare (Figure 5.44) as the simultaneous operation of three global systems, linked by the flows of treatment, payment and information. In the Life Course global theme, people managing illness in various ways exchange information and treatment with various types of providers in the Provision Network. Those providers receive compensation for their services through several means and under diverse market configurations in a Payment Exchange. Crucially, the dynamics of the systems described in these themes are explained in a separate Change theme that captures mechanisms associated with events and interventions. Together these themes and flows represent, as a narrative model, how healthcare systems work. It shows in particular how the global systems mutually constrain one another, producing complex behaviours that are due, not the sole activities in any one system, but to their behaviour they produce as a system.

5.7.1 Micro and macro levels of representation.

The fundamental and defining feature of the model that emerges from this analysis is that it represents the *aggregated behaviours of interacting actors* rather than the *interacting behaviours of aggregated actors.* Combining these concepts, the analysis reveals healthcare as a *system of systems* both as smaller systems nested within larger ones in tree-like structures, and as intersecting systems in lattice-like structures where relationships cross boundaries of some systems in forming other systems.

A generic healthcare system is revealed (Figure 5.45) by the analysis as a system of systems, emerging from the properties and behaviours of individual actors - Persons, Providers, Regulators and Firms, and connected to one another in various configurations by flows of information, services and funds. Properties change from time to time, propagating through the linkages and revealing the dynamic nature of healthcare, and exposing various responses to intervention.

The global themes synthesize recurring lower level basic and organizing themes of thematic analysis graphically and as narratives and translate as specifications that are packaged in the SysML repository. These specifications in turn serve as templates with which to configure and simulate particular models of healthcare systems either as they exist in the real world or as they might be improved with changes in policy.

5.8 Summary of the themes model of healthcare systems – SMoH-t

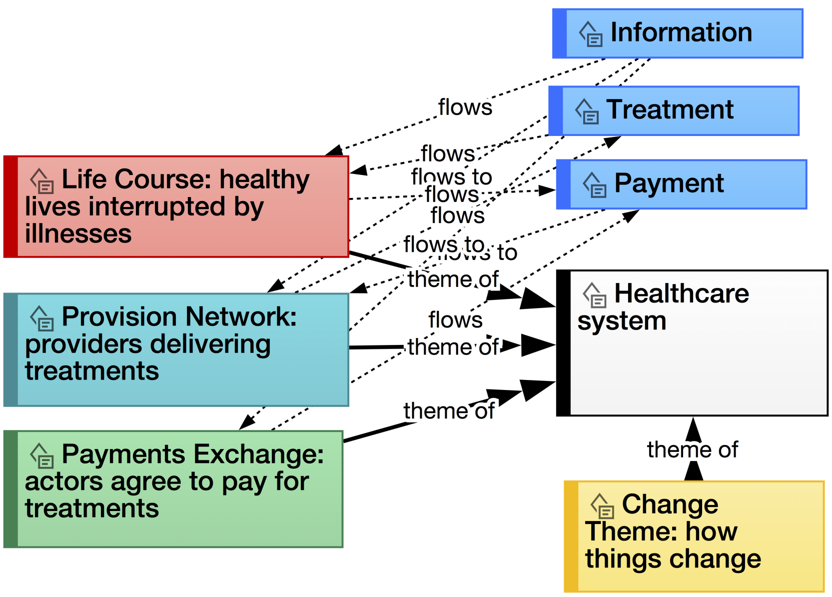


Figure 5.45: Healthcare is a system of three systems (Author's own).

In summary, the themes model lays a foundational representation of constructs, theories and observations of healthcare systems in the real world. The connection between this representation and its real world targets is a vital link in the chain of validity on which all models rely in satisfying their epistemic requirements and in meeting the expectations of those looking for predictions and explanations.

The themes model of healthcare systems, SMoH-t, in Figure 5.45 reveals a pattern in which each global theme contains the other through the flows that connect them. It is a pattern that unifies and extends a broad range of theoretical and empirical knowledge of healthcare as a system. As such, it can be proposed as a systems theory of healthcare. It adds depth to the theory embedded in the frameworks reported in the literature (subsection 3.1.3).

When this initial version uses the narratives and the natural and technical language that domain experts use in their writings, it maintains clear traceability to the underlying theoretical and empirical sources with which the representation is constructed. This version of the model uses a style built around the codes and network diagrams of template and thematic analysis and in particular of ATLAS.ti, the content analysis application used in this research. The style is readily interpreted as richly representing the underlying system structures and behaviours, but does so in narratives and graphics that are less readily adapted to exploration and explanation. The next version of the model restates the findings of this chapter as an ontology using a style that adds specification to the underlying system representation while preserving its essential constructs.

5.9 Chapter summary

This chapter traces the development of SMoH-t, the first thematic version of the systems model of healthcare. The essential entities –actors and flows – form the basis of mechanisms. These are combined as progressively higher layers or ‘themes’, producing at the total level a system of three systems. The change theme emerges as particularly relevant.

Chapter 6

Version 2: Systems Model of Healthcare as an ontology - SMoH-o

This chapter refines the findings reported in the previous chapter by restating with greater precision the narratives and constructs of the thematic version of the systems model of healthcare. The restatement uses the methods of Model Based Systems Engineering (MBSE), applying the graphic and structural elements of SysML, a language used to specify complex systems. Following an overview of the restated model, the chapter translates the narrative activities of the thematic model as behavioural diagrams. It then restates the entity narratives as blocks associated with the behaviours. In the subsequent sections, the blocks and behaviours are represented as systems within systems, ultimately representing healthcare as a single, connected system of systems.

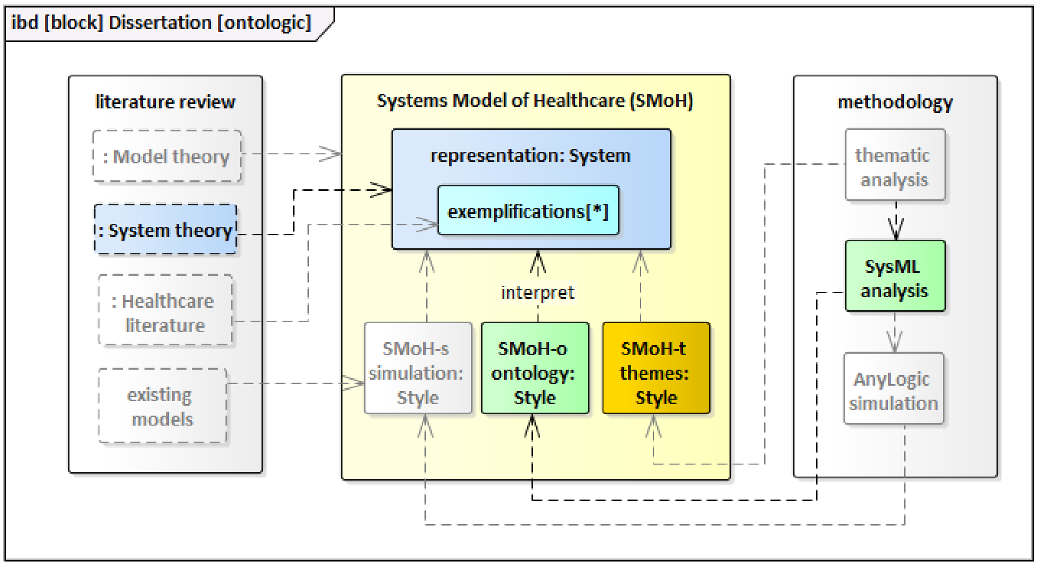


Figure 6.1: Using SysML analysis, systems theory is applied to the representation in the themes style, restating it in the style and language of systems (Author's own).

As an enhancement of the narratives and network graphics of the themes version in chapter 5, this version of the systems model of healthcare preserves the *representation* and *exemplification* already established in the themes version, while restating the entities and activities as specifications in SysML, a language specially designed to develop and describe systems visually. Figure 6.1 shows that the methods of analysis and specification that are central to SysML as a structured approach to engineering design are applied to the thematic model that emerges from the first thematic analysis method. It exposes the system's properties and methods at its various levels, including the events and mechanisms that produce change. This model's data structures and diagrams are assembled as an *ontology* of healthcare systems. This version of the model serves as a second, more structured interpretation of healthcare as a system.

The ontology version restates the themes version in a style that more precisely describes the representation as a system. It is an ontology of entities and activities that combine as mechanisms and that function at several levels. The translation from narratives and networks to the graphical formalisms of the systems language preserves the meanings of the underlying microfoundations, emerging here in a framework of multiple agents that shares some of the characteristics of microsimulation models reported previously in the review of the literature (subsection 3.1.7). Using a subset of SysML language elements, it refines those constructs by using consistent specification of properties and behaviours, and by adding functional detail to the relationships that connect the systems entities to the events that produce changes.

Within the systems model of healthcare, the ontology as a repository is fully contained and accessible as a project in Enterprise Architect[1], a software application designed to support system analysis and design in several languages including SysML. Selected documentation of the repository is attached in Appendix C. In the following sections, selected exemplars demonstrate the genesis and shape of this version.

6.1 Overview of the systems model of healthcare, *ontology* version - SMoH-o

This second version of the model – SMoH-o – is an ontology of specifications representing healthcare as a whole system. It provides a view into the representation of healthcare that is more consistent and precise than that described through thematic analysis in the first version. Where that version uses a style that combines narrative texts and network graphics, this version specifies the system's entities and activities – the mechanisms and their interactions – using standard symbols, data structures and diagrams. These specifications are

[1]http://www.sparxsystems.com/products/ea/

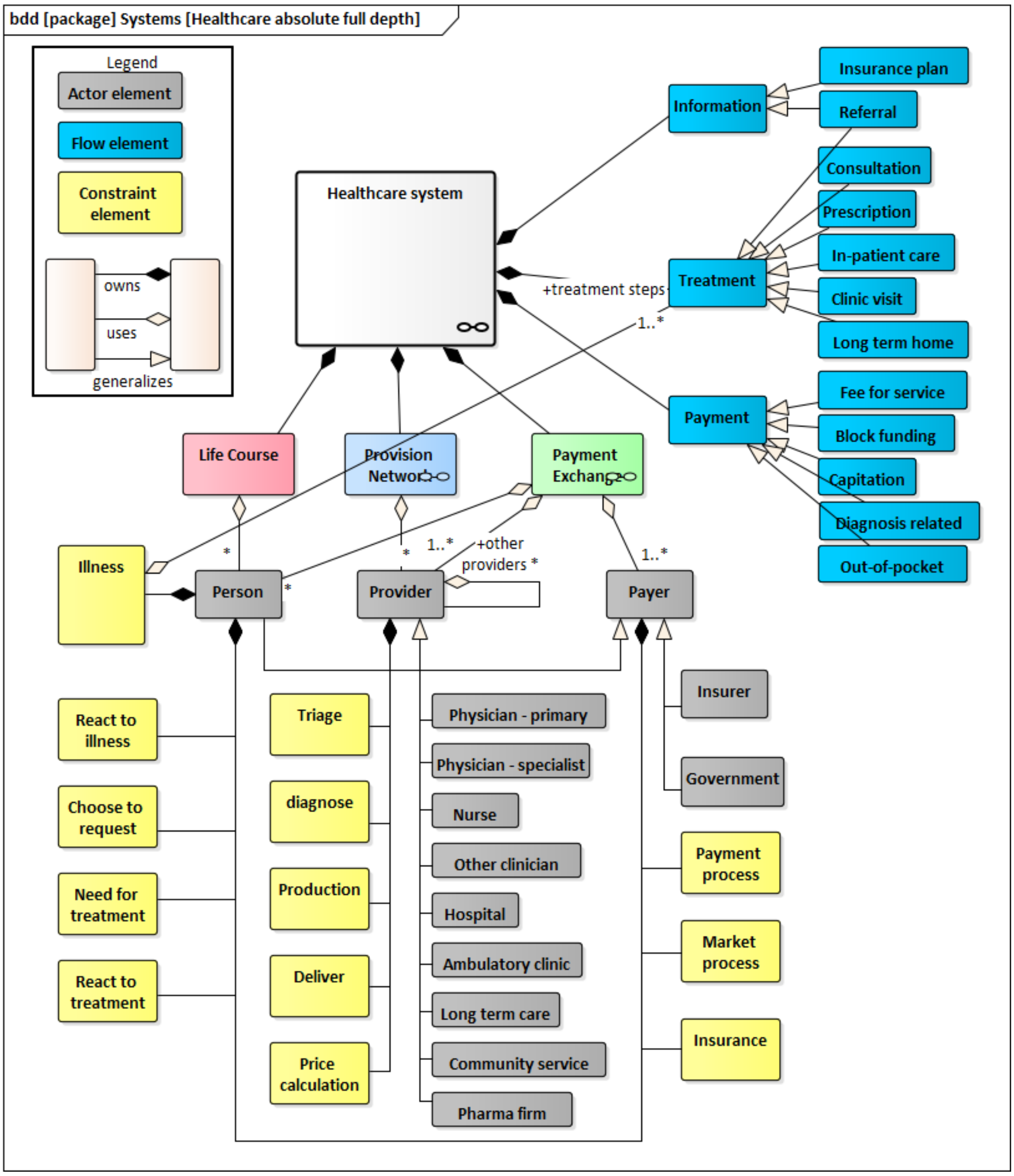


Figure 6.2: This schema is an ontology that interprets the systems model of healthcare as a hierarchy of actors, flows and constraints (Author's own).

maintained as a repository.[2] With its consistent and precise style, this version of the model has advantages as a shared means of conceptualizing and evaluating reform and innovation in healthcare systems.

In representing healthcare as a multilayered system ontology, the model produces a schema (Figure 6.2) showing the various entities as interrelated blocks. There are three main types of blocks – Actor elements, Flow elements and Constraint elements. The main themes and the healthcare system itself are also depicted and highlighted as blocks.

The relationships among the blocks take two general forms. The first form indicates the elements that make up the system: those that the system *owns* (depicted by filled diamond shapes at the head of connecting links) or uses (depicted by open diamond shapes). The second form indicates hierarchical variation.

A healthcare system is composed of three major elements, the Life Course, Payment Exchange and Provision Network systems, and of three types of Flows. Each of these systems includes sets of Actors – Persons, Payers and Providers – who exchange flows of Information, Treatment and Payment. These blocks are included in the respective systems, but are not owned, since they exist in other, unconnected contexts that may influence their states and even their behaviours. For example, Person actors are also included as consumers in the larger economic system, which may determine and possibly change their socioeconomic status. Such inclusion in more than one system is a mechanism of exogenous change, seen from the context of the healthcare system.

The second relationship is hierarchal, depicted by arrows at the head of the connecting links. This relationship indicates the block at the head of the arrow *generalizes* some behaviours of the downstream blocks in some ways. Although the underlying mechanisms are fundamentally similar and specified by default in the generalized block, they are implemented in different ways in each of the specialized blocks. So, for instance, a generalized *flow* is generated in one block and influences another block. Specialized blocks – information, treatment or payment – generate their content in different ways. The same type of relationships applies to the several ways that diverse Providers produce and deliver treatment.

The schema also includes constraint blocks owned as properties by each of the Actor types. These specify the outcomes of relationships in formalisms(section 4.4.2). Individual constraint blocks specialize a general constraint

[2] A *repository* is simply a digital storage location in which the data structures and diagrams are maintained, updated and accessed.

block. Provider types *produce treatments* in general by converting resources by various mechanisms, each defined as a particular production function of some properties and parameters. Primary physicians specialize the production function to reflect, for instance, the use and limitations of their own time to produce an office visit and prescription for medication. A hospital on the other hand, specializes its production function to reflect the use of staff time and use of real and consumable assets to produce a period of stay as inpatient.

As depicted in the schema, this combination of variance and invariance in both properties and in actions exposes mechanisms that help explain[3] consistencies and differences among observed real world healthcare systems.

6.1.1 Repository as packages of structures and behaviours

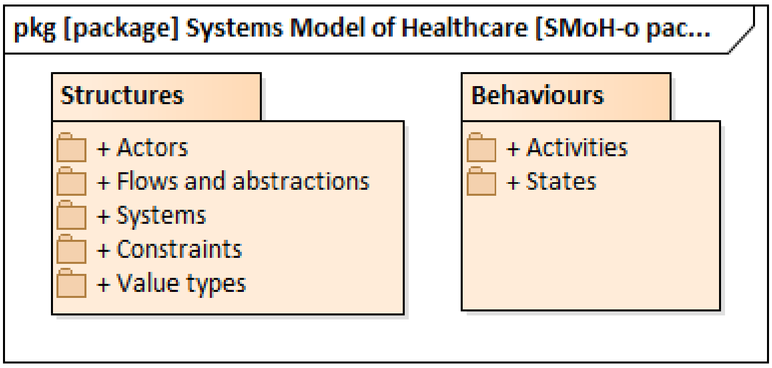


Figure 6.3: The repository's organization reflects the principal dimensions of systems (Author's own).

The translation process begins with themes, since the behaviours must first be exposed in those contexts before they can be added as functions to the specifications of the entitiesThe model's repository is represented as two orthogonal dimensions of the model's representation. It is composed of packages (Figure 6.3) holding, respectively, the structural specification of the model's elements, their properties and linkages, and the behaviours that specify the dynamic and causal relationships that link those structures as mechanisms. The logic of the system's mechanisms is specified in activity diagrams that allocate activities and actions to associated actors or abstractions. The system entities are specified as blocks, both with the structural properties and relationships, and with the behaviours they employ in contributing to mechanisms.

6.2 Healthcare activities as behaviours

The organizing themes in the previous *themes* version are first interpreted as activities and actions allocated in lanes that represent the appropriate actors

[3]This echoes the premise discussed in the introductory chapter (section 1.1) .

and abstract constructs. The activities and actions are incorporated as functions and methods of the relevant actors in a later process. In this section, each behaviour is expanded and specified.

6.2.1 Behaviours identified in the Life Course theme

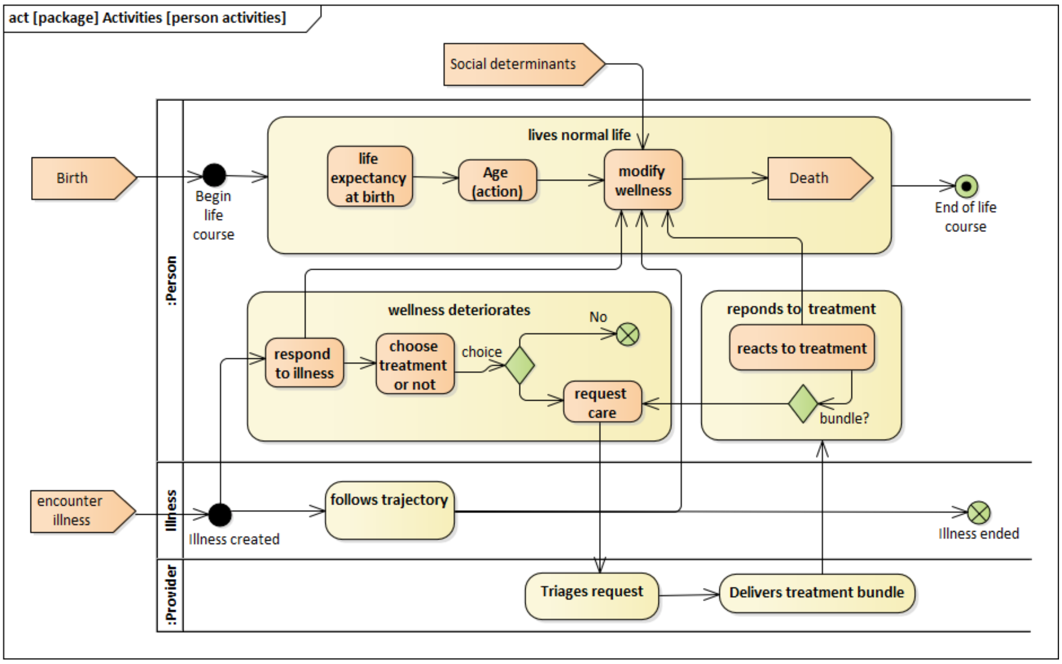


Figure 6.4: Behaviours associated with the Life Course global theme are represented as overlapping activities (Author's own).

The basic and organizing themes of the Life Course global theme (subsection 5.5.1) in the previous version of the systems model are depicted in Figure 6.4, translating the entities and activities. The overall lifecycle is shown as an activity element that begins with birth and ends with death. The activities associated with illness episodes are shown in a separate activity element, while a third element depicts the mechanisms associated with treatment. Each of these activity elements contains actions that represent separate functions and methods, and they are assigned to the Person actor. The connections to actions and activities allocated to other actors are addressed later in this section.

Living life as an activity of a Person

The *lives normal life* activity represents the *Person is born, ages and dies (section 5.4.1)* basic theme within the Life Course global theme by actions internal to the activity.

It includes an estimated value for the expected life span of the Person, based on a calculation of the prevailing life expectancy at birth for the larger society.

For the purposes of the model, the aging process simply indicates the passage of time, and otherwise does not result in any salient changes in the Person's state. The death event marks the expiry of the life span. Conceptually, the value of the life span may change in the model, based on exogenous determinants such as life style behaviours and environmental conditions.

The *modify wellness* action in particular represents the changes that happen at the onset of and during an episode of illness, whether treatment is delivered.

With the triggering of the *death event*, the Person entity is not removed from the model; its state is changed to inactive and the changes in state are retained as time dependent variables for retrospective analysis.

Illness as a cause of deterioration in wellness

The second organizing theme in life course is depicted in the *wellness deteriorates* activity element in Figure 6.4. The activity itself is allocated to the Person entity, but it is initiated by an external *encounter illness* event that introduces a new abstract entity to the model. This instance of an illness is associated with the Person entity, and remains in the model until the person is no longer ill. With the onset of illness, the person responds to the illness, triggering a reduction in wellness through the *modify wellness* action. This leads to a *choice* action on the part of the Person to request professional care. If the choice is to do so, the Person initiates a *request* which is sent to a Provider. The Person's wellness continues to be modified by the illness trajectory.

Treatment as a response to illness.

The third activity translates the *response to treatment* organizing theme. Once a treatment bundle has been delivered, the person reacts to that treatment. Depending on the nature of the treatment and its therapeutic relationship to the precipitating illness, the reaction to treatment moderates the effects of the illness. If this is sufficient to offset the effects of the illness, the illness entity associated with that person is removed from the model. However if the treatment bundles with it needs for further treatment, it leads to an initiation of a new round of request and delivery of treatment.

6.2.2 Behaviours identifies in the Provision Network theme

The Provision Network block translates the organizing themes in the Provision Network global theme (Figure 6.5) as four major activity elements. The actions in the first element are related to the response to a request received, and in the model occurred immediately as a reaction to that request. The remaining

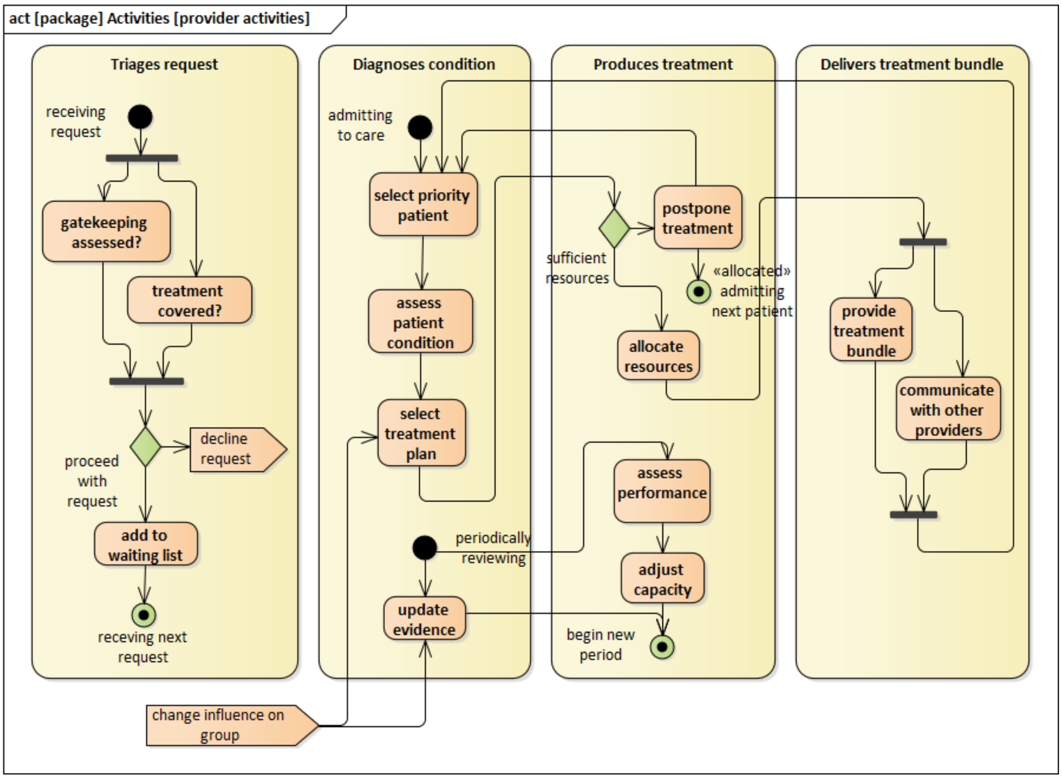


Figure 6.5: Behaviours associated with the organizing themes in the Provision Network are represented as a sequence of process activities (Author's own).

activities may occur on completion of this initial *triage* activity, or may be initiated at a later time.

Triage

The reaction to receiving a request leads to two concurrent actions, both of which determine whether a request received has been appropriate. The *gate-keeping* requirement applies if a request has been submitted to a specialist provider without the prior authorization of a primary care *gatekeeper*, where that is mandated in the system that is modelled. The second action determines if suitable remuneration is associated with the treatment required. If both of these requirements are met, the request is accepted and displaced in sequence for treatment. This activity is initiated by the receipt of any request, and concludes with the appropriate disposition of the request.

Diagnose

The *Diagnose condition* activity begins with an action to respond to the request of another patient. In the model, this action is a choice by the Provider of a patient already in the waiting list, using an algorithm that accounts for urgency and sequential position on the waiting list. The next action represents a determination based on available patient information of the diagnosed illness. This determination, within the model, may be subject to stochastic variation to represent the uncertainty associated with clinical diagnosis. Once a diagnosis has been determined, the provider selects a treatment plan. This third choice action exercised in the diagnostic process is subject to stochastic variation, to represent the variation in approaches to treatment observed in the real world.

Produce

Once a treatment plan has been selected, and subject to availability of capacity, necessary resources are allocated and assembled. Within the model the relationship between treatment components and resources is represented by a constraint that includes parameters unique to the particular provider. This allocation depletes resources available to the provider. If sufficient resources are not available, the sequence is terminated, treatment for the patient is postponed and the cycle for the time period ends.

Deliver

The delivery activity initiates two parallel actions. The first action sends the treatment as a package to the person initiating the request. The second action represents a treatment plan that involves not only the delivery of a treatment directly to the patient, but also includes communication with other providers whose services may also be required to complete or continue the care of the patient. Once the sequence of diagnosis, production, and delivery has been completed for the selected person, the process begins again with the next patient, until the cycle for the time period has been completed.

6.2.3 Behaviours identified in the Payment Exchange theme

The five organizing themes of the Payment Exchange (subsection 5.5.3) are represented by three main mechanisms. The first mechanism relates to the routine compensation of providers by several types of payers. The second relates to the market pressures to create periodic adjustments to the prices of services into the expenditures by payers. The third mechanism relates the influence of the external environment in determining the changing prices which goods and services are based.

Routine payment

The mechanisms that compensate providers for services delivered operate on a regular and routine basis. Where funding flows from a third party payer, whether an insurance firm or government, the model implements a periodic

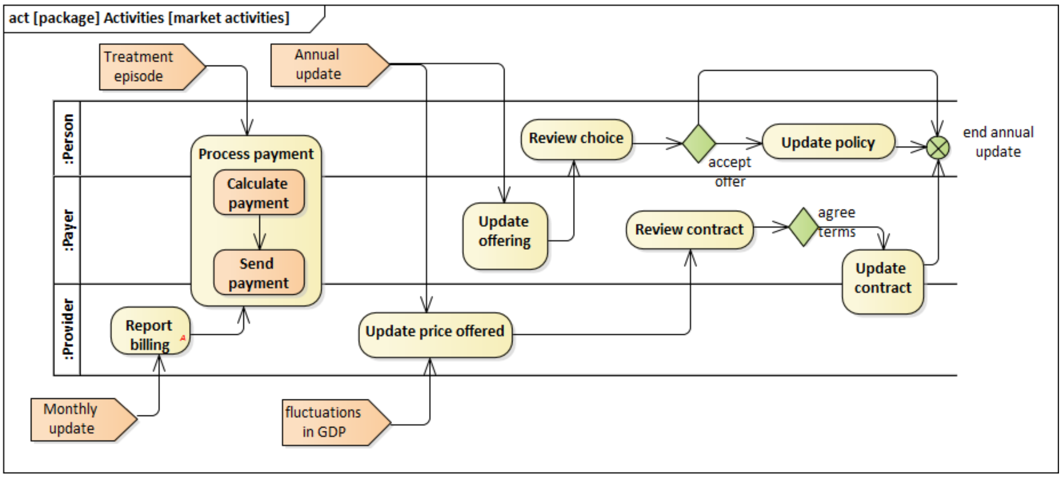


Figure 6.6: Behaviours associated with the organizing themes in the Payment Exchange are represented as three main mechanisms (Author's own).

update event that initiates a report of activity to the payer. The Payer in turn calculates payment on the basis of the funding agreements in place at the time and flows the appropriate payment to the provider. For simplicity of representation, out-of-pocket expenses paid by individual patients on the basis of their treatment episodes, flow through the payment process implemented by the Payer.

The *calculate payment* action in the model implements as constraints the various payment methods, including per diem, capitation, and the various types of activity-based funding. This is a central feature of the model in representing the diversity of funding and expenditure control arrangements across the various healthcare systems.

Market pressures

A second set of mechanisms operates on a much longer cycle in the model. These reflect periodic changes to pricing and volume levels through various means. The activities depend on the insurance regime in place. Funding supported by government either directly or indirectly may be capped to contain expenditures within larger government expenditure targets. Funding provided through standalone insurance agencies including commercial firms and statutory *sickness funds* may be constrained to remain within the financial performance goals of the paying agency. Within the model, the associated activities are triggered on an annual basis, and the associated limits are set on the basis of simple choice mechanisms.

Where individual insurance plans are permitted within the system, a similar review and reset process is implemented. Once again, depending on the insurance regime, individuals may elect to update the policy or to cancel a policy unless prohibited by regulation.

External influences

The third mechanism reflects the influence of the larger external economic environment, particularly as it sets price levels for labour. These influences are beyond the control of the parties to the pricing agreements, but their influence is reflected as a factor in the calculation of prices.

6.2.4 Behaviours in the repository

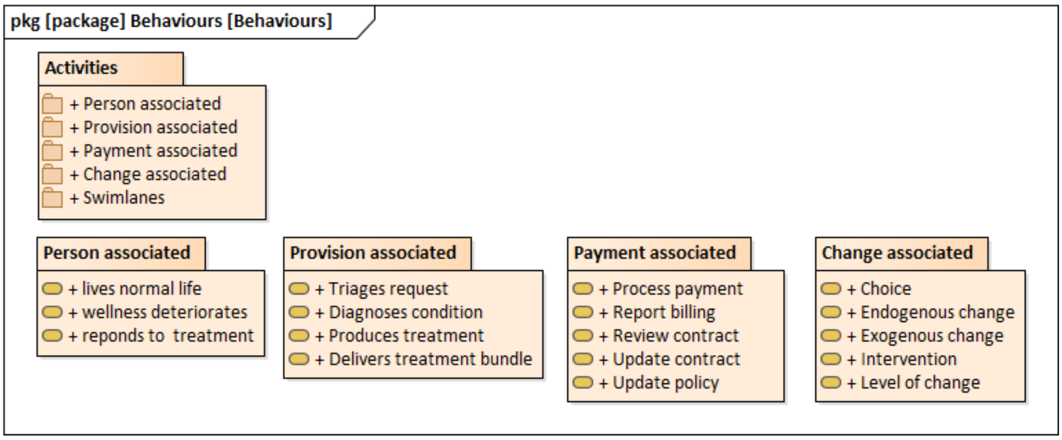


Figure 6.7: The activities associated with the main actors and change mechanisms are organized as packages in the repository (Author's own).

The activities diagrams are grouped in packages within the repository (Figure 6.7), in five recognizable groups. The first four correspond to the organizing themes in each of the global themes (including the Change themes) of SMoH-t, the thematic version described in the previous chapter. A fifth group (Swimlanes) included in the Activities package captures the essential nature of *mechanisms* as associations between elements and activities. The the lower packages summarize the activities described in this section.

6.3 Healthcare entities as blocks

This section interprets as *blocks* the entities that were identified in the themes version of the model. A SysML *block*, described more fully in section 4.4.2, in essence identifies the properties and activities associated with a given construct. This section discusses *illness* as a central entity in a healthcare system model, and continues to detail each of the three actor blocks.

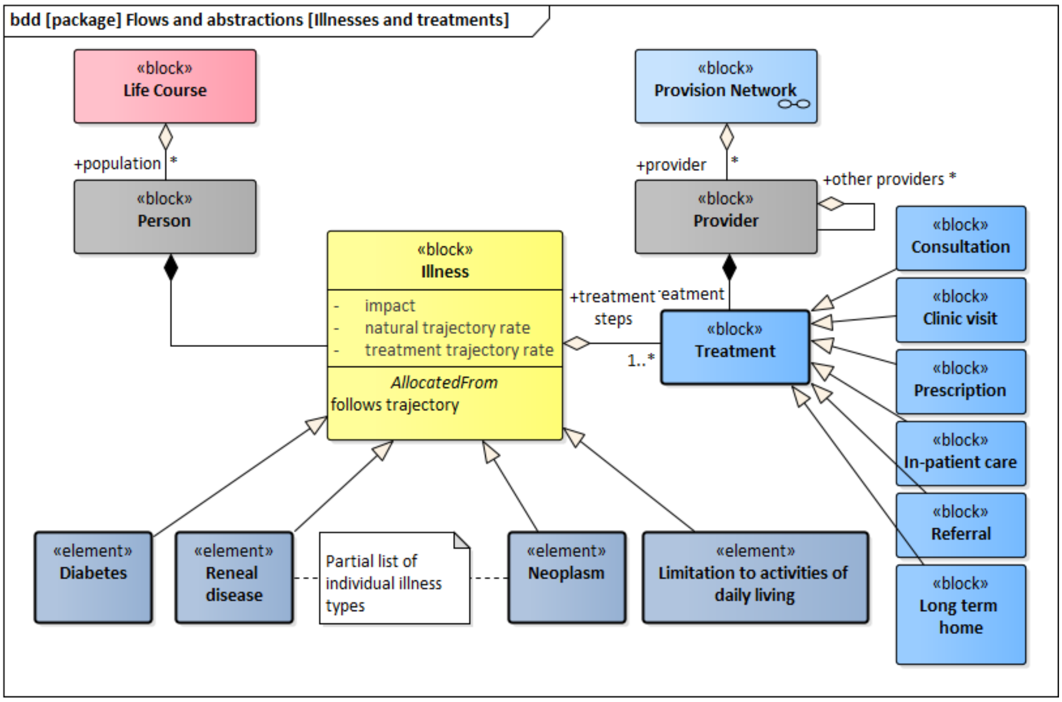


Figure 6.8: Illness is central construct, impacting a Person's wellness and guiding a Provider's choice of treatment (Author's own).

6.3.1 Illnesses specification

Illness as an abstraction is specified with a block that formalizes the impact on wellness over time and under various conditions of treatment (Figure 6.8). Since the construct is an abstraction that captures functional effects on the properties of other entities, it is specified as a *constraint* block, a type of block that shares the structural features of standard blocks, capturing properties as values and actions as functions. However, in depicting an abstraction, it also include a formal statement of the relationships between the properties of related blocks.

The formalism is modified in each of the specialized versions of block, reflecting variations in the magnitude of the impact over time and the relationship wilt treatments of various types. At a parsimonious level, illnesses may be categorized simply as acute and chronic, based on the profiles of impact and trajectories of recovery.

An illness comes into existence as a transient element on the occurrence of an episode. When a Person encounters an illness, it has an adverse impact on the person's wellness, which is followed by an ongoing rate of change in wellness following a natural trajectory. If the Person requests and receives treatment, the treatment modifies the earlier trajectory by improving its rate of change positively.

6.3.2 Person specification

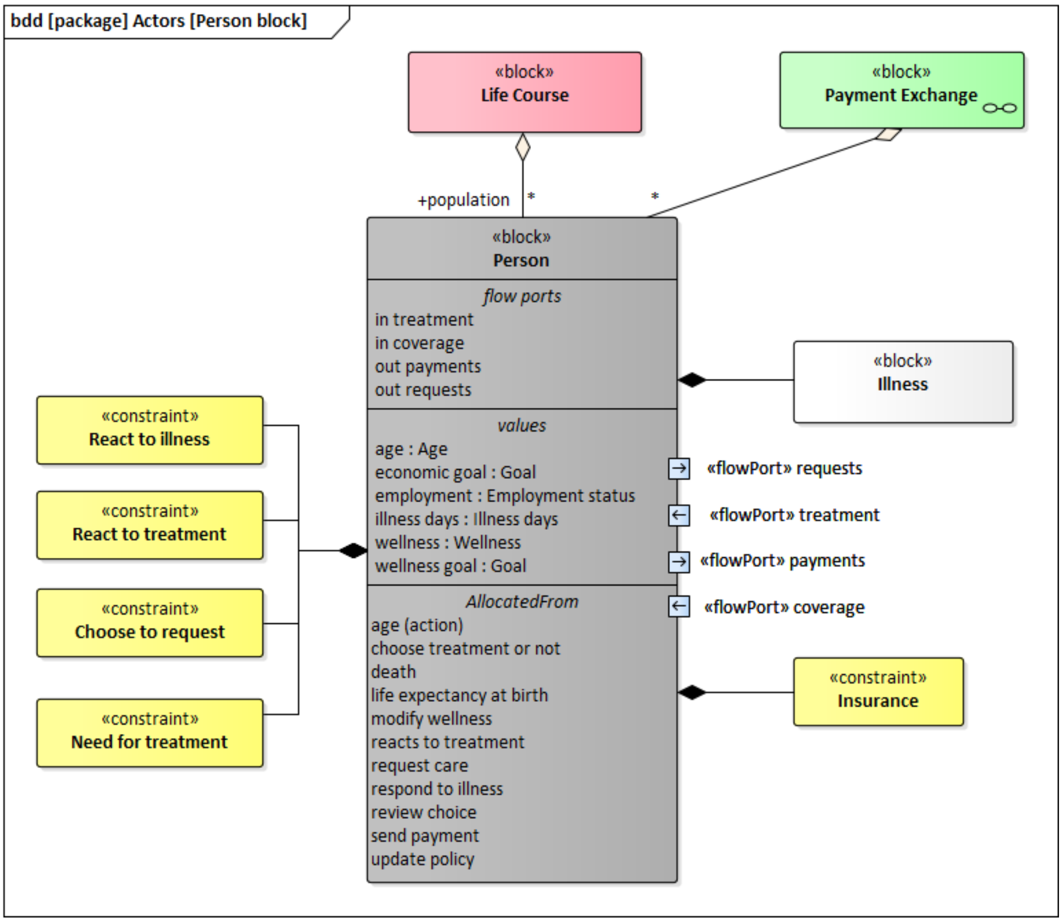


Figure 6.9: Person translated as simple SysML block (Author's own).

The Person block with attributes and behaviours is shown in Figure 6.9. Although the term *patient* is used to describe a Person under some circumstances in the healthcare system, it is internally consistent to regard Patient as a special state of a Person. A Person changes state when her level of wellness has dropped to a level where she needs the support of another person to manage her illness.

Properties

The properties of the Person actor are readily translated as numeric and logical values. They include the basic demographic variables and measures of employment and insurance coverage. The Person block represents the central wellness property in two ways. The first is as a numeric value, set to a nominal value by default to represent the Person's normal, undisturbed state.

Behaviours

The activity diagrams (e.g., Figure 6.4 reviewed in the previous section discussing behaviours) allocate actions to various actors, based on analysis of the themes version of the model. These allocated activities are confined in the Person specification, where they contribute to representing mechanisms involving Persons.

Complex behaviours

Three behaviors of the Person warrant more complex specification. The occurrence of an illness evokes a reaction on the part of a Person where her level of wellness changes over time and based on the type of illness. SysML translates this reaction as a constraint block that specifies it as an algorithm. Similarly, a separate constraint block specifies the *changes in response to treatment received*. Algorithms in the third constraint block capture the variables, the weights and the logic involved in the *choice to request care.*

Person state chart

A special SysML construct captures the changes that occur in the Person's state during episodes of illness and treatment. The state machine diagram in Figure 6.10 indicates that under normal circumstances a Person is the *well* state (blue). When that Person encounters an illness, she *reacts to illness* and moves into the *unwell* state (pink) and by default to the *not-in-care* substate (red). Based on the Person's properties including age, sex, socioeconomic status and insurance coverage, she may choose to request and be admitted to care. (The model specifies as a boundary condition that she immediately requests treatment).

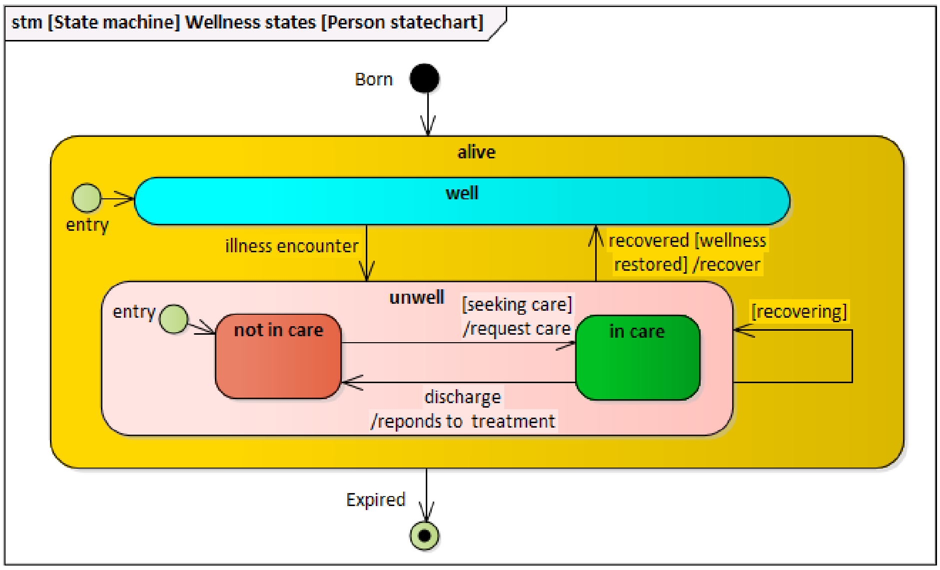


Figure 6.10: The state chart associates activities with transitions between states of wellness and of care (Author's own).

When or if treatment is received, she moves into the *in care* state (green). When treatment is complete, and she *reacts to treatment* successfully, she returns to the *not in care* state.

When the recovery time is reached (either with or without treatment as appropriate) she moves back into the *well state*.

This rendition of the movements between states illustrates how the complex behaviours of the thematic network are translated as a single structure of simple events and behaviours in SysML and in code.

Connecting ports

The activity diagrams show the sequences in which actions lead to other actions. When these actions occur between different actors, and in particular when they involve the exchange of *Flows*, SysML specifies the points that connect the action in one to a reaction in the other. These points, known as *connecting ports*, are shown graphically at the perimeter of the sending and receiving blocks. Their relevance is better demonstrated in the context of the higher level systems in section 6.4 where the main systems of healthcare are discussed in greater detail. That section resumes elaboration on the application of connecting ports.

6.3.3 Provider specification

The Provider block with attributes and behaviours is shown in Figure 6.11.

Heterogeneous providers

The Provider and the Treatment in the behaviours are represented as generalized actors and abstractions. The particulars of the types of Provider and of Treatment are relevant in the larger systemic contexts that will be addressed later. As described in the themes analysis, each Provider type is associated with one or more Treatment types. When the boundaries of the model extend to include these distinctions, the specialized versions of the blocks apply.

6.3.4 Payer specification

The Payer specification captures the generalized functions in the Payer block, and specific variations in types of capacity in the specialized versions. These account for the heterogeneity in funding and in behaviour among various countries.

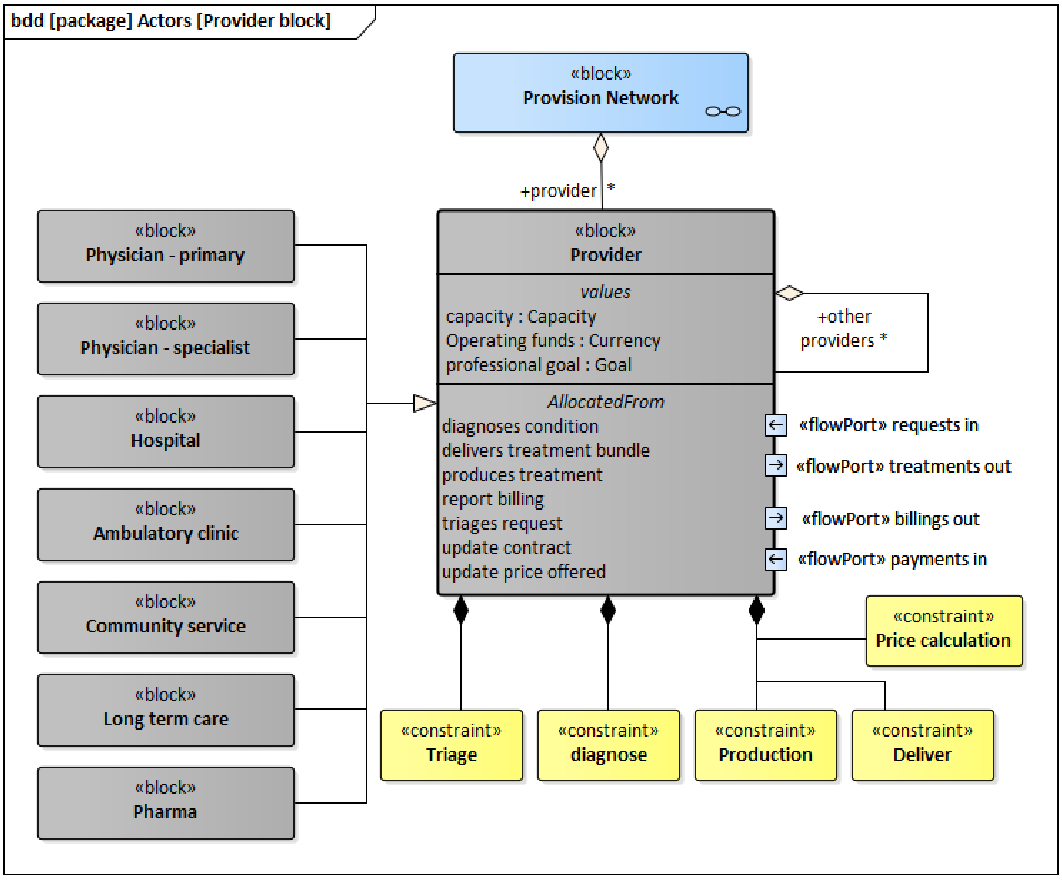


Figure 6.11: Provider translated as a simple SysML block (Author's own).

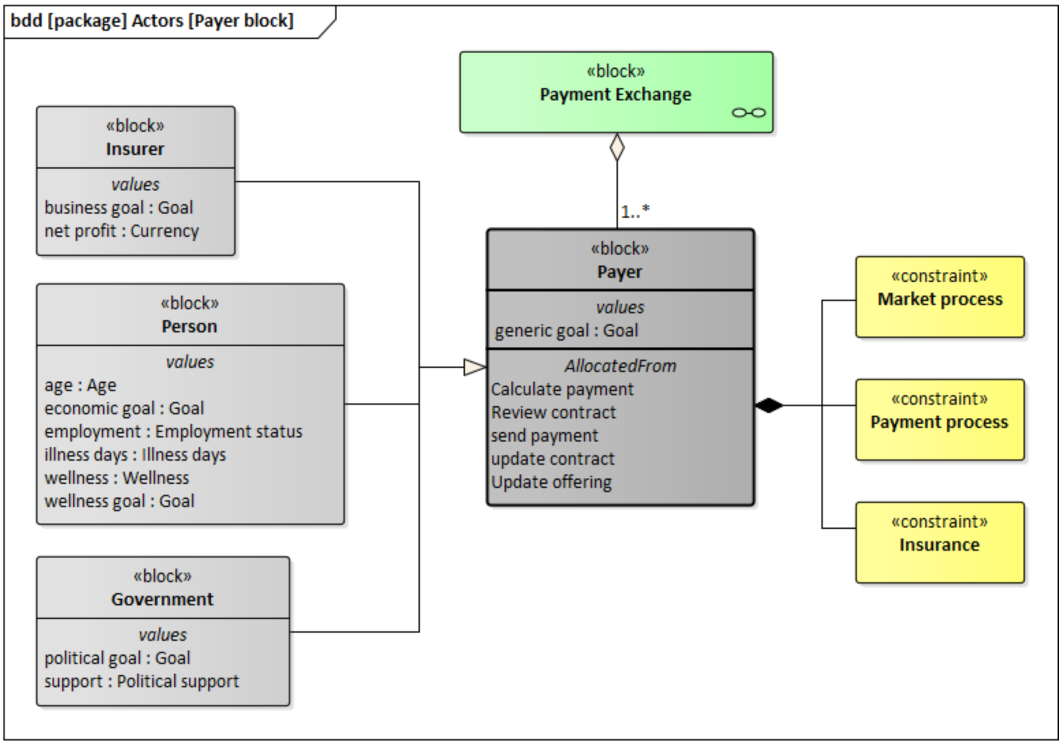


Figure 6.12: Specialized types of Payer implement various properties and common activities (Author's own).

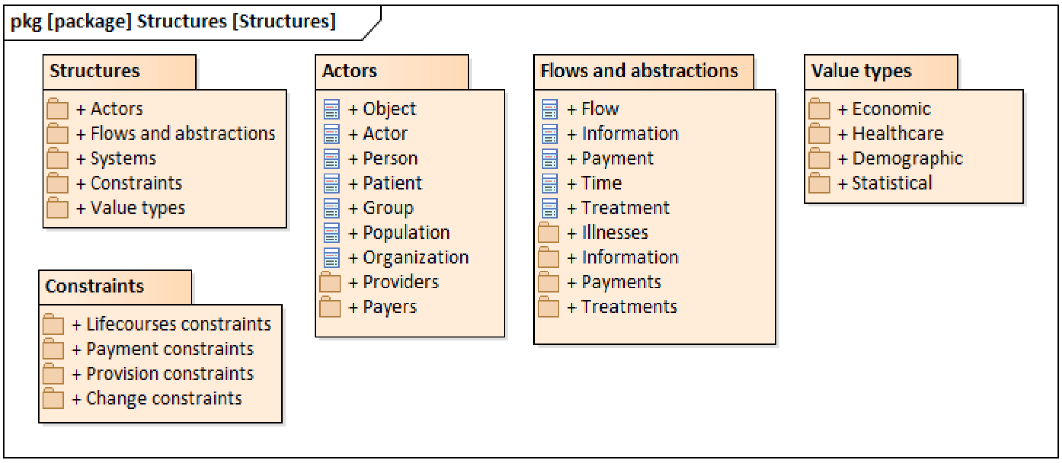


Figure 6.13: The structures associated the main actors and entities are organized as packages in the repository (Author's own).

6.3.5 Blocks in the repository

This section has interpreted as *blocks* the entities that were identified in the themes version of the model, where each block specifies its properties and the activities. The organization of these structural specifications as packages in the repository is depicted in Figure 6.13. The diagram includes details of the packages containing actors, and the flow and constraint abstraction. It also includes specifications of various value types used within those specifications. The *Systems* item in the structures package relates to the systems of healthcare, which are addressed in the next section of this chapter.

The activities associated with the main actors and change mechanisms are organized as packages in the repository.

6.4 The main systems of healthcare

This version of SMoH translates the global themes as high level blocks. In doing so, the specification preserves the aggregate nature of the thematic representation. Each of the high level systems represents the collective mechanisms of its constituent parts. In the case of the Provider Network system, these include not only the flows of information from and treatment to individuals in the LifeCourse system, but also internal relationships among the Provider elements themselves. This reflects in explicit terms some of the emergent behaviours imputed by some scholars to real world healthcare, where the overall behaviour of the (Provider Network) system is not adequately explained by the separate behaviours of the individual members. Similar emergent phenomena arise from the relationships internal to the Payment Exchange system. Elements of the LifeCourse system tend in general to behave independently of one another. Within the confines of this main system (but not necessarily with the top level connected system) the behaviours of the high level system resemble the behaviours of the individuals.

6.4.1 Life Course main system specification

Life Course block definition diagram

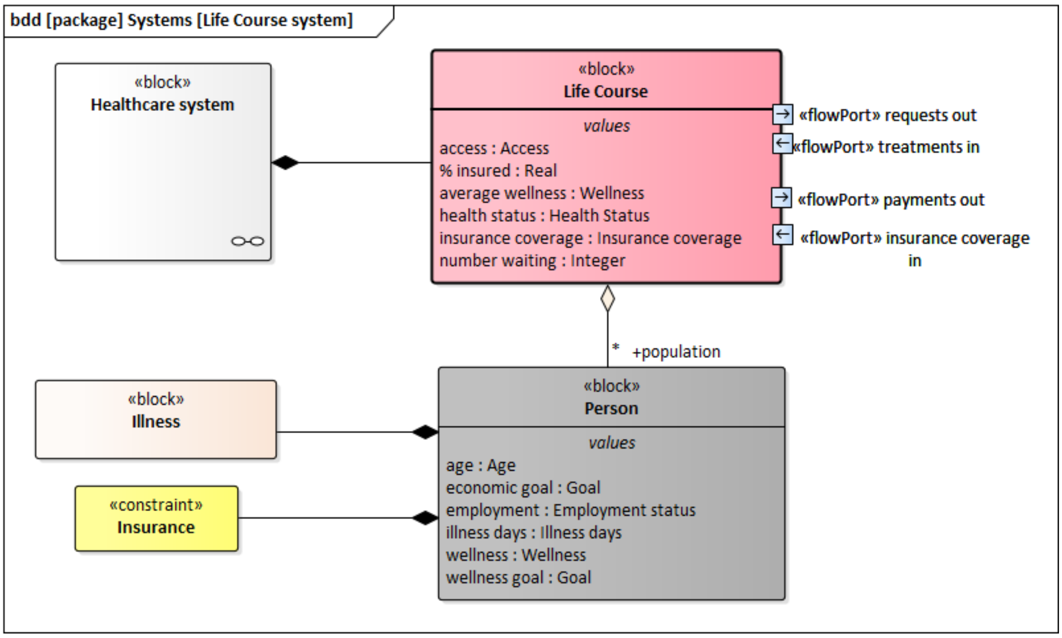


Figure 6.14: Life Course system includes a set of Person blocks, aggregates their values and routes their Flow in and out (Author's own).

The Life Course system restates the Life Course global theme (subsection 5.5.1) in the themes model.

The system is a collection of Persons as a population (Figure 6.14). Of note, the values observed at this main system level exemplify the indicators relevant to the performance of healthcare systems, such as health status, access and insurance coverage. It has access to and can aggregate the values of the individual elements. This includes direct population measures not readily observable in real world systems, such as average wellness, statistics of Persons waiting, or numbers in need of but without access to care.

The block includes ports that route inwards and outwards the various flows that originate with and terminate at the individual Persons. These flows are observed and reported at the system level.

Life Course internal block diagram

The connections within the Life Course system Figure 6.15 are trivial; the diagram shows the direct connections to and from the individual elements in the population, and visibility of value properties on each one.

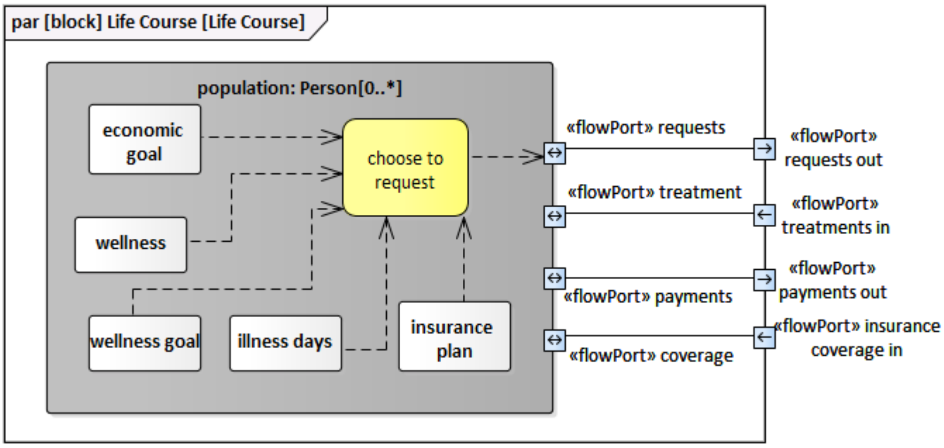


Figure 6.15: Internally, the Life Course system is specified with simple connections of incoming and outgoing Flows (Author's own).

In the larger context of the whole healthcare system, the LifeCourse system presents as single source of treatment requests, and as a destination for treatments allocated and delivered.

6.4.2 Provision Network main system specification

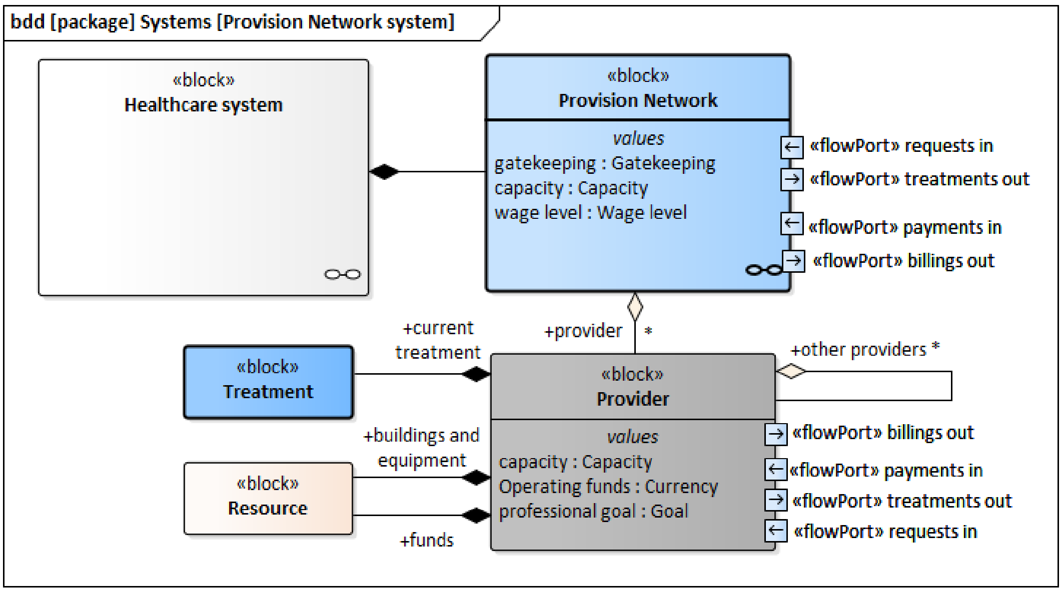


Figure 6.16: The Provision Network is a block in which Provider agents are connected and aggregated (Author's own).

The Provision Network system restates the Provision Network global theme (subsection 5.5.1) in the themes model .

The system is a collection of Providers of several types, shown as a block definition diagram (BDD) in Figure 6.16. Once again, it has access to and can aggregate the values of the individual elements, overall and as groups.

The block includes ports that route inwards and outwards the various flows that originate with and terminate at the individual Provider. These flows are observed and reported at the system level.

This main system is distinguished by the relationships among the individual Provider elements – depicted by the *other Providers* linkage at the upper left of the block representing the Provider in Figure 6.16 and through which they communicate and coordinate. It is noteworthy that scholars and practitioners point to the inadequacy of these connections in the real world. In implementing the model, this variable behaviour would warrant examination and experimentation.

6.4.3 Payment Exchange main system specification

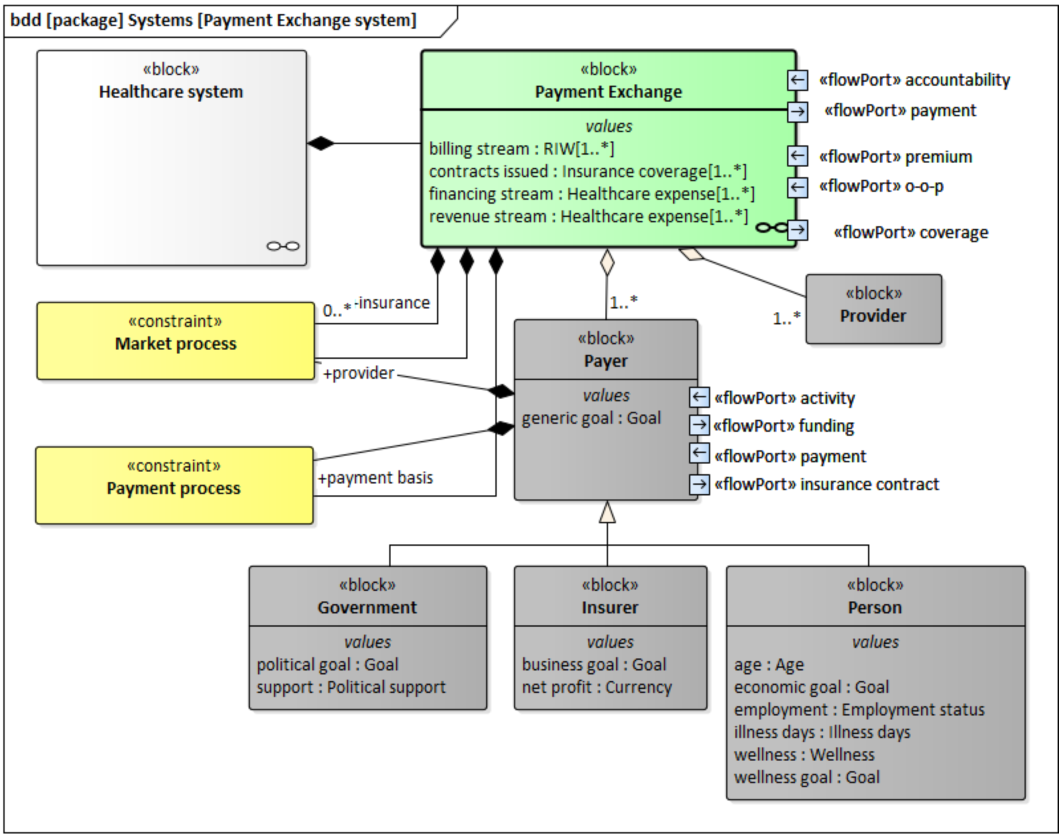


Figure 6.17: In the Payment Exchange system, Payers of various types flow Payments, provide insurance, and set prices (Author's own).

In the themes model, the Payment Exchange global theme is described Figure 5.39 in terms of Payers making payments to Providers and of processes that influence and determine prices and therefore expenditures in providing care. The ontology model restates the underlying representations as a block definition diagram (Figure 6.17).

The exchange is a collection of Payers of various types, each with its own values that influence how funding, risk and allocations take place. The mix of types arises in the broader institutional context, and may change over time, such as when a country moves from one insurance regime to another – from private and commercial to universal tax funded, for example.

The indicators of interest at the system level are the measures of flows in and out. Although these originate at the level of individual payers, their cumulative values are of interest from the overall system perspective important to assessment and planning.

Payment process constraints

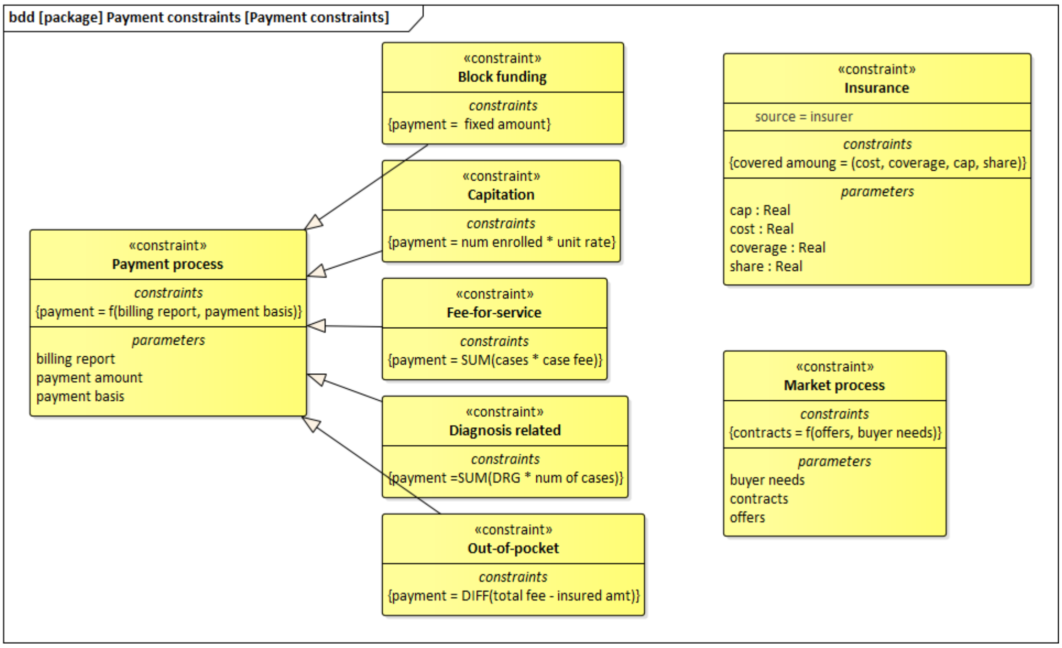


Figure 6.18: Constraints specify the payment, insurance and market relationships in the Payment Exchange system (Author's own).

The Payment Exchange differs from the other two systems in that it owns two constraints that operate at the system rather than at the micro level of an individual element. The first constraint specifies payment processes, the algorithms by which funding is calculated in the exchange. The second represents overall mechanisms if they exist.

Two essential mechanisms characterize this system as an exchange in the broad sense of the term. The first is the mechanism by which payments are calculated. These determine the levels of the outbound flows that link this system with the Provision Network, where as inbound flows they influence the production of treatments. The second is the mechanism whereby prices are set between the Providers as suppliers, and the Payers (typically as erstwhile consumers of services on behalf of insured Persons.) These mechanisms are shown in Figure 6.18 as generalized *constraints*. They are shown as available within the exchange system, but they occur as instances associated with the actors in the exchange, and are discussed in greater detail later.

The internal relationships Figure 5.40 in chapter 5 identified several forms that payment may take. These differ not only in the quantity of the payments delivered, but in how those amounts are calculated. Payments are specified in the ontology model using constraint constructs. Figure 6.18 shows that, in general, a payment is calculated on the basis on the information provided by a Provider, and by applying a particular calculation algorithm. At this level, the constraint serves as a template; in each instance of the model, different constraints specialize the general template by specifying the appropriate algorithm.

Using constraints in generalized and specialized forms in this way captures the diversity of payment flows observed in the real world. It allows that in block funding, for instance, the volume of services does not enter into the calculation[4]. At the same time, capitation funding is based only on numbers of Persons of currently enrolled patients.

Insurance constraint

For the purposes of the model, health insurance is an arrangement that calculates and makes payments to providers on behalf of a plan holder. The factors, conditions and algorithms are specified as a constraint. In general, the payment is assessed on the basis of the price of a treatment, but in its various specialized versions it may include additional factors to account for limitations to types of treatments, maximum or minimum amounts and co-payments.

The variety of specialized insurance constraint is owned by the Payment Exchange System, but an individual Person will also own on instance if she has coverage of any kind. From this perspective, the constraint is applied to calculate out-of- pocket payments, and enters into the individual mechanism of choosing to request care.

6.5 SMoH-o: Healthcare as a system of systems

This chapter has described a healthcare system as an ontology, where a block represents the system as a whole. Structurally, this block is specified and summarized in two complementary diagrams. Figure 6.19 specifies that three systems and three flows exist within the context of a healthcare system, while

[4] Although for monitoring purposes, reporting these volumes to the payer may still be a contractual requirement.

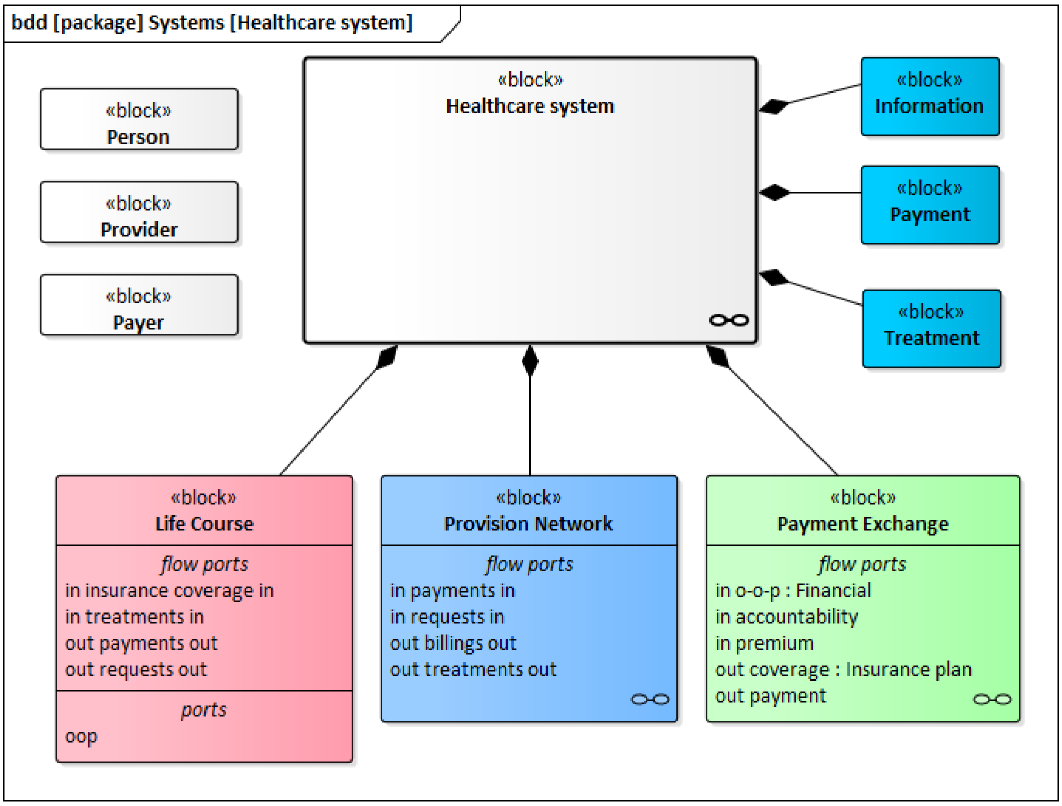


Figure 6.19: The ontology version specifies the constructs of healthcare in a block definition diagram (BDD) (Author's own).

Figure 6.20 the relationships between those top level system elements. In the language of SysML, the inner workings of a whole healthcare system are represented in an internal block diagram (IBD, Figure 6.20) showing Life Course, Provider Network and Payment Exchange as three component subsystems. The actor types are noted but not connected in the diagram. Individually, they are represented within each subsystem, along with the flows between them - Treatment, Payment and Information in various forms. Their aggregated indicators are represented in the main system.

6.5.1 Functional view of healthcare as a system

Some variables of interest are available at this top level. Each is a statistic (typically an average or mean) relating to properties of lower level elements or systems within the model; these were discussed in earlier sections of this chapter. However, that estimating qualitative relationships among these top level variables is not supported by any specified functional mechanism. Such estimates are typical of techniques that "allow the data to speak" without prior reliance on theory. While this model can support this type of representation, its epistemological leanings, and its methodology tends toward the position Wolpin (2013) takes in availing of relevant theory to understand better the

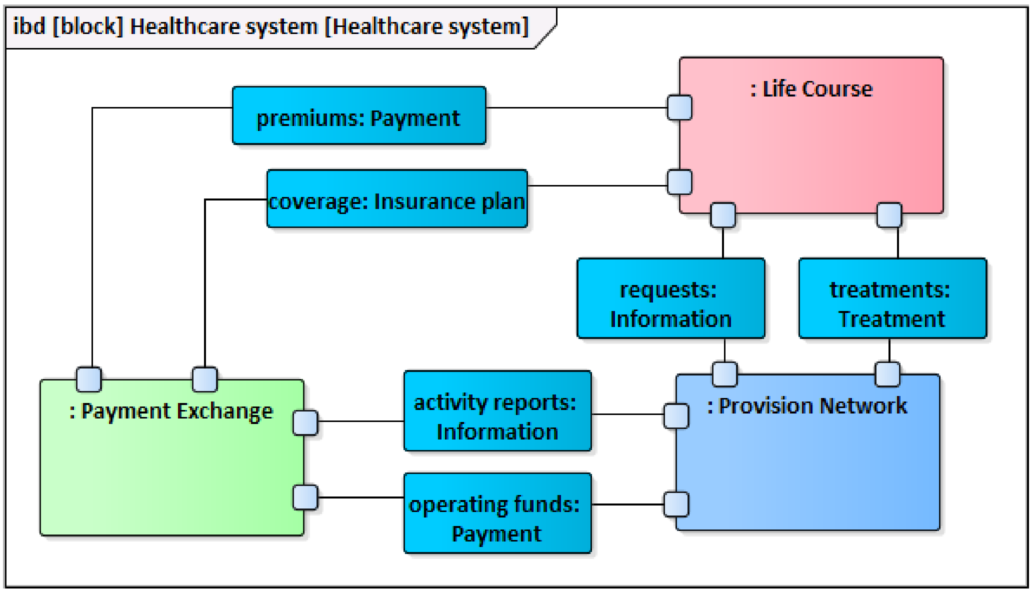


Figure 6.20: The internal block diagram (IBD) of a healthcare system specifies that flows link the main systems of healthcare (Author's own).

relationships within the system. When research attempts to predict, it must often go beyond available data and include theory as well.

6.5.2 Flows and connecting ports.

The internal block diagram (Figure 6.20) includes connecting ports in a functional context. The ports at the perimeters of the main systems are *bound* selectively to one another by lines that represent the connections. This exemplifies both the boundaries of the respective systems (especially the subsystems that correspond to the layering of themes in the thematic model) and the constructs of the entities that flow in these exchanges. These constructs (connecting ports, connections and flows) are essential in specifying the healthcare model, and by inference instances of real world healthcare systems, as a single coherent system.

6.6 Summary of the ontology model

This chapter has described the ontology version of the system model of healthcare. The model is presented as an ontology maintained in the repository or specifications; specifications are documented as data structures and the special-purpose diagrams. Together they can be used to illustrate and explain the various mechanisms contained in the representation at the heart of the model. The strength of this version lies in the structural and behavioural representation. As a communication tool, however, it is primarily accessible to users who are familiar with the SysML language. This precludes its use by many professionals who are committed to reform and innovation of their healthcare systems, but whose skills do not include that familiarity.

Although the specification of the generic healthcare system is a representation in its own right, its primary value is as an intermediate step between the coded data retrieved from the expert literature and some form of simulation accessible to users who are not skilled in the arcane methods of systems science. In the next chapter, a third version of the model is presented using a style that extends access to the underlying representation, and adds visual and dynamic dimensions intended to promote greater understanding and explanation.

6.7 Chapter summary

In this chapter, the earlier thematic version of the model is specified more robustly as an ontology – SMoH-o. Using the graphical constructs of SysML, the behaviors and entities of healthcare are assembled and connected in diagrams that capture and expose their structures and behaviours. This version of the model again reveals the layers of systems in healthcare and the key role of change as an essential mechanism.

Chapter 7

Version 3: Systems Model of Healthcare as a prototype simulation - SMoH-s

This chapter applies the formal, ontological specification of healthcare systems, reported in the previous chapter, as an interactive software simulation. It describes the implemented version first at the uppermost, integrated level, followed by descriptions of the component systems and of the agents they contain. The Systems Model of Healthcare - simulation version (SMoH-s) – is also applied as an experimental laboratory in representing the healthcare system in the Netherlands[1] over three decades.

This version of the systems model of healthcare is a simulation that implements in software the specifications of the previous ontology version, exposing for the user the mechanisms of the representation, visualizing its variables as time trends and its structures as hyper-linked displays. It presents the model as an interactive application designed for configuration to denote a target healthcare system, and for exploration of scenarios as experiments.

In implementing specifications from the ontology version of the the healthcare model, this version crucially preserves the semantic *representation* and *exemplifications* that emerge in the thematic analysis of SMoH-t , thatbare specified on the ontology version SMoH-o, and that lie at the core of the systems model, SMoH. The software architecture of the simulation is designed in the Unified Modeling Language (UML), used widely to design software applications. Since UML is the parent language that SysML extends, the conversion path from the ontology version to the simulation version is short. Furthermore, the AnyLogic development platform on which the model is implemented uses a graphical development environment that replicates several SysML symbolic structures, making the conversion pathway even shorter.

The development platform incorporates three approaches to modelling – it supports (i) system dynamics and (ii) discrete event approaches in addition to (iii) agent based modelling – allowing incorporation of elements of existing models built with similar approaches.

[1]This country was chosen as an exemplar since the evolution of its healthcare system has been examined and reported widely in the healthcare literature.

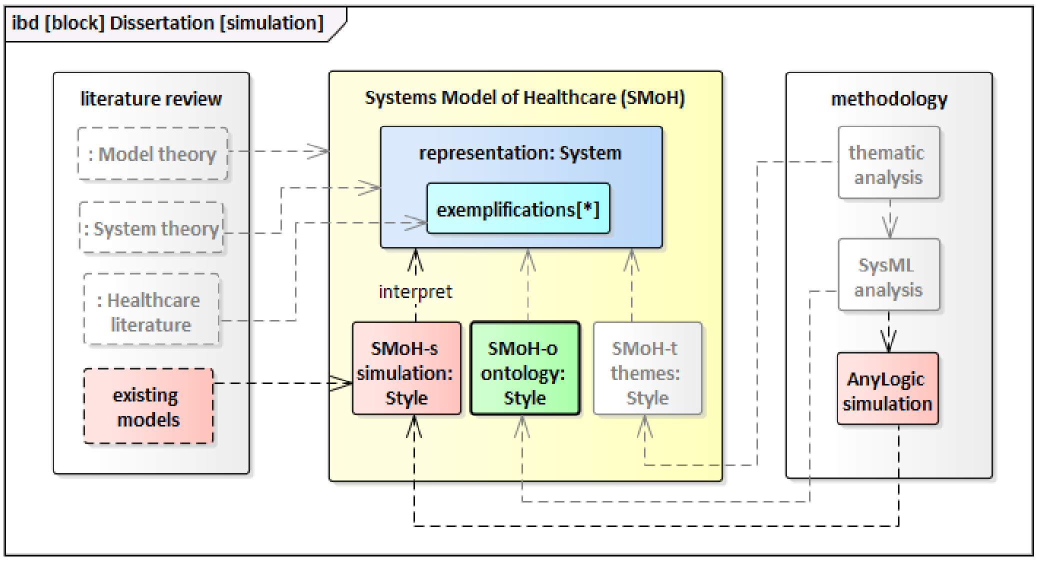


Figure 7.1: SMoH-s, an empirical simulation representing healthcare, uses a software development platform, and extends some existing models to implement specifications found in the ontology version (Author's own).

The model itself is implemented and fully contained as a project in AnyLogic, which includes an integrated development environment (IDE) with rich visualization features and produces documentation of its elements and procedures, including specification of components and details of custom programming code. Appendix D provides a sample, for illustration purposes, of the extensive documentation that lies in the background of the simulation version of the systems model of healthcare (SMoH-s).

The following sections include static representations of the model as exemplars of its capabilities and results. Understandably, the full dynamic and interactive capabilities of the model cannot be demonstrated within the static constraints of this written dissertation.

7.1 Overview of the systems model of healthcare, *simulation* version - SMoH-s

This third version of the model – SMoH-s – is a software simulation that represents healthcare as a whole system, exposing its dynamic and causal nature for exploration and experimentation, visualizing the representation graphically, dynamically and interactively. It draws from the repository of the ontology version of the model, implementing the standard symbols, data structures and diagrams with software modules that execute, as functions, the behaviours previously specified. Configured with appropriate parameters and with available data, the simulation model exposes trending dynamic variables as time plots and preserves resulting data as time series for later analysis.

The simulation model visualizes values of the various indicators and parameters of systems and levels of the underlying representation of healthcare. As an implementation of specified components, it instantiates a representation of a target healthcare system by assigning values to some of the parameters and variables. Using the scheduler built into the development platform, the output dependent variables are calculated according to the connections among the modules, and the results displayed at various levels of the model's interface.

7.1.1 Healthcare system as an agent based model

The implementation of a selection of the system's constructs is an exemplar of a model that can be used to explore and explain how a healthcare system works, and to assess outcomes under various configurations and conditions. The implemented subset of the ontology model is sufficient to satisfy minimally the requirement of representing the system's *wholeness* and of revealing some *explanatory* capabilities. It enables configuration of the generic model as an instance of a target system, with real or synthetic data and supports visualization of selected properties at several levels and across all systems.

The simulation application is implemented as a top level agent, representing the ontology, that contains member agents representing the Life Course, Provision Network and Payment Exchange systems. It also contains collections of agents representing the populations of Actors – Persons, Providers and Payers, including their specialized subtypes. The simulation application is designed for configuration to denote a target healthcare system as an experimental environment.

7.1.2 Perspectives on the simulation version of the systems model of healthcare

This chapter describes the simulation model from three perspectives. It addresses in the first section (section 7.3) the structures, from the top level view of the complete model, to views of the main systems (LifeCourse, Provision Network and Payment Exchange) to the details of individual actors and abstractions that function within those systems.

In the second section (section 7.4), the model is approached from a dynamic perspective, showing how actions and events become functions in the programming environment producing observable changes in state in model time[2].

[2] *Model time* distinguishes the representation of elapsed time in the artificial world of the model from that of the real world.

The third section (section 7.5) describes how the model's design, which includes heterogeneity of structures and behaviours, may be configured by users to examine scenarios of interest. This includes a report on and results of an experiment that simulated the evolution of particular healthcare system.

7.2 Top level view of the healthcare system

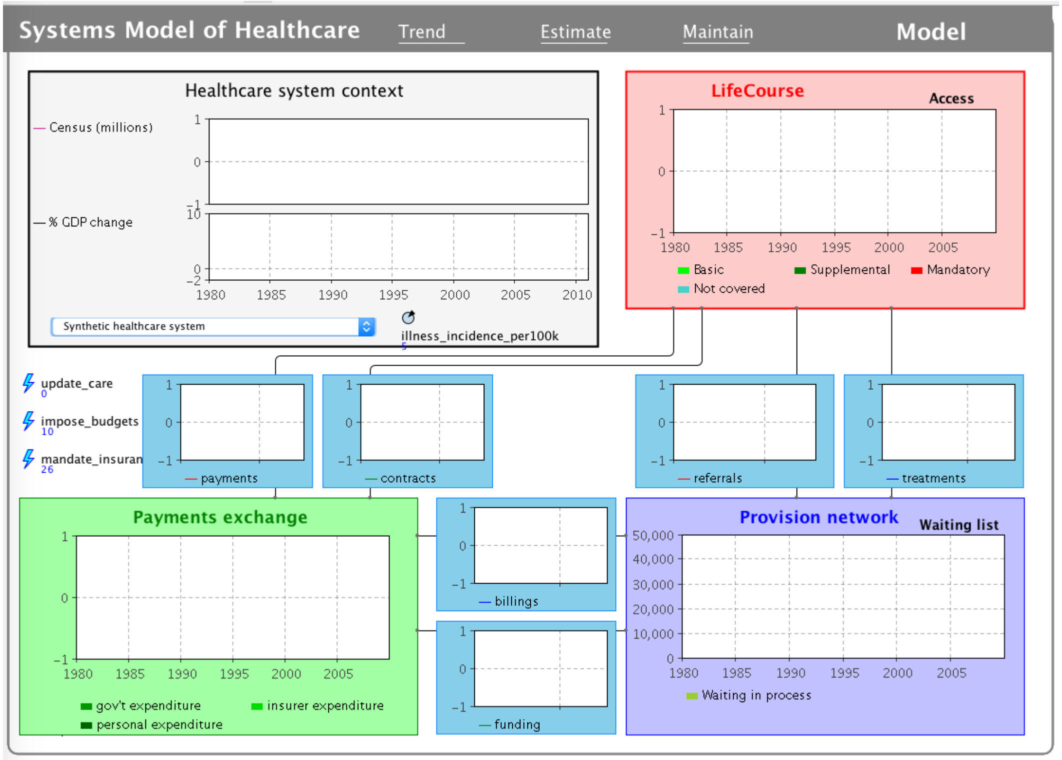


Figure 7.2: The main window of the simulation model visualizes time trends in the three main systems and in the flows that connect them (AnyLogic screen capture).

Figure 7.2 shows the output display at the main level of the simulation interface. It is structured in four quadrants, displaying basic simulation parameters in the the upper left, and selected indicators from each of the top systems in the remaining three. The basic parameters display trends in two exogenous variables – population and GDP growth, along with a drop-down option to select from pre-programmed scenarios.

The three coloured panels correspond to the main systems in the ontology version, Figure 6.20 and in the thematic version, Figure 5.2, and continues with the colour coding used there. They display trends for selected indicators of interest, one each for the Life Course (pink), Provision Network (blue) and Payment Exchange (green) main systems.

Finally, inserted between the major panels, this level also displays trends for the values of each of the flows that connect and unify the whole system.

This completes the top level view of the simulated system. The run time version of the application includes controls t o start, pause and end simulation runs, along with utilities to record and save configurations and outputs of experimental runs.

As presented here, SMoH-s is an instrument with narrow practical application; its boundary conditions limit the scope of its surrogative reasoning to high level mechanisms and events only. Within the scope of this dissertation, the implementation is designed to establish the feasibility of a software implementation; it is limited to a set of indicators relevant to trends and counterfactual scenarios in a single healthcare system for which some comparative historical data is available. However, a much more robust and fulsome simulation model *could* be created in the future by any researcher willing to simulate a broader set of conditions and settings.

7.3 Main systems of healthcare

While the top level of the simulation visualizes the main systems of healthcare (Figure 7.2) and exposes a primary indicator of interest in each of the three main system panels, the software implementation enables live exploration, in greater detail, of each of the main systems. Selecting any one of the panels reveals for the use a new view of the selected system. Each of these is replicated in the sections below.

7.3.1 Life Course system view

The interior view of the Life Courses system in Figure 7.3 shows in greater detail the specification of the first main system. This includes a display of constituent properties (in the upper left corner) along with the behaviours and events implemented at this level (in the left margin). The remainder of the view displays active representations of indicators and an optional animation of Persons as icons.

A window on the population indicators

The view of the Life Courses system shows in its primary display the time plot (pink panel) of the variable selected for inclusion as the essential indicator of LifeCourse behaviour at the top level of the healthcare system. It also includes time series of other variables of interest (e.g., care status, self-reported health status). When configuring a simulation experiment, these secondary time plots are individually interchangeable with the top-level plot.

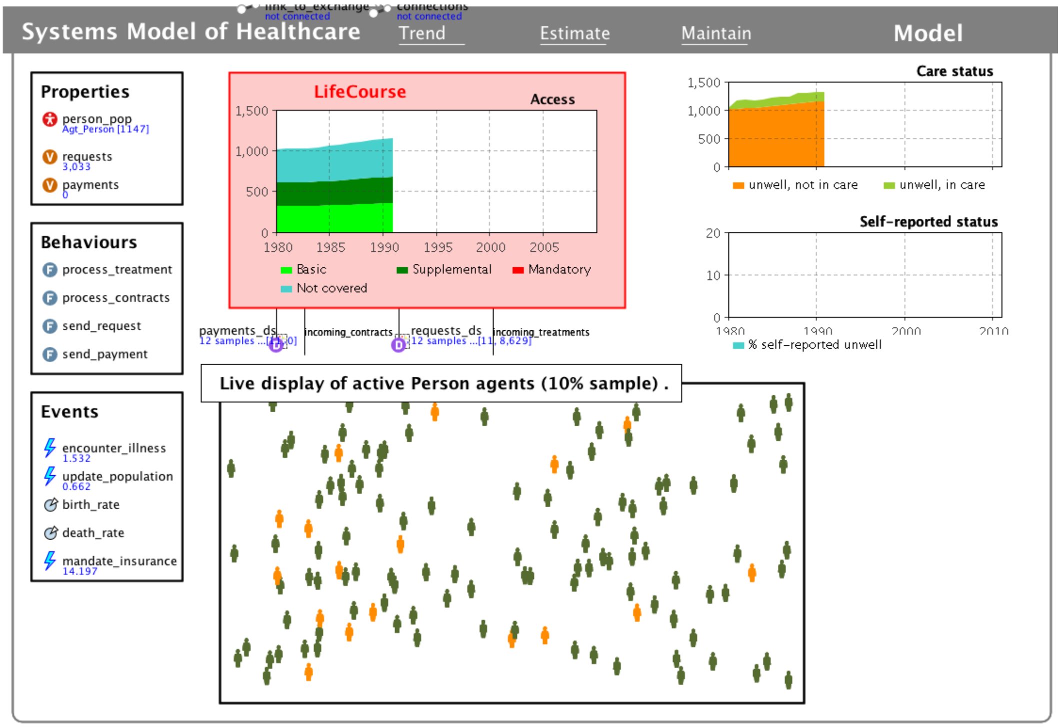


Figure 7.3: An interior view of the Life Courses system displays elements, behaviours, events and key time trends (AnyLogic screen capture).

Properties of the Life Courses system

The *person_pop* property in this view points to a collection of Person agents that is the population associated with the model. The size of the collection is set at the beginning of the simulation and reflects the changing census during the simulation run.

Numeric variables track the number of *requests* and total values of *payments* in a given period. These are simply counts and accumulations of the flows into this main system.

Behaviours in the LifeCourse system

The behaviours at this level are functions that manage, collectively, the routing of various types of flows into and out of this main system. In the LifeCourse system these are simply *pass-throughs* of the underlying flows of individual Person agents (described later). For example, every request for care that a Person agent initiates is passed through the *send_request* at LifeCourses level, and similarly ever treatment delivered by a Provider passes through the *process_treatment* at this level. Although these functions do not directly affect the state of the LiefCourse system, they allow the collection of measures of activity at the aggregate level of the population. The *process_contracts* and *send_payment* behaviours serve the same measuring function within the model.

Events driving the LifeCourse system

Scheduled events trigger periodic changes in the population census as configured by birth and death rates, and illness occurrences configured to preset distributions. This implementation of the simulation supports scenarios that include, as an experimental option, the introduction of mandatory health insurance at a pre selected time in the simulation run.

Implementation of events, both through configuration of exogenous variables and through the simulations endogenous and emergent interactions, is a vital feature of the simulation version in implementing the causal mechanisms that support explanation and understanding. This distinguishes the dynamic interpretation of the simulation version (SMoH-s) from the earlier static interpretations, either as a structured formal ontology (SMoH-o), or as layers of narrative and networked themes (SMoH-t).

Individual illness encounters are triggered randomly by the *encounter_illness* event at the system level, representing incidence rates for a given population. In this prototype implementation, the illness type is limited to one generic type, but the underlying design allows for multiple types and for incidence profiles based on various probability distributions. The *update_population* is triggered annually to add and remove Person agents from the population, based on configured *birth_rate* and *death_rate* parameters. The *mandate_insurance* event is available for triggering at a selected time in an experimental scenario.

Extended set of measures and Indicators in the LifeCourse system

Figure 7.3 displays as its main feature the trends over time of indicators of interest relevant to the Persons simulated in the model. In this configuration, the main measures (pink panel) of interest indicate the levels of access to care across the simulated population, mirroring the same panel in the top level display.

This system level view also displays other variables, including the fractions of unwell Persons in the various levels of care, and a display of the fraction of the Population self-reporting their health status as *unwell*. This latter is an example of an indicator that can measure unmet needs readily in the model, but only with difficulty in the real world.

Optional animation of Person states

In its lower region, this view displays a fraction of Person population visualizing dynamically their transitions between the *well* and *unwell* states. This display supports understanding of the inner workings of the model and hence of the target healthcare system, and is useful in the early stages of exploration. However, processing this animated display diverts valuable computational capacity away from the more important aspects of simulating the agents and their interactions. It is implemented as an optional feature that is readily bypassed for more serious experimentation and explorations.

7.3.2 Provision Network system view

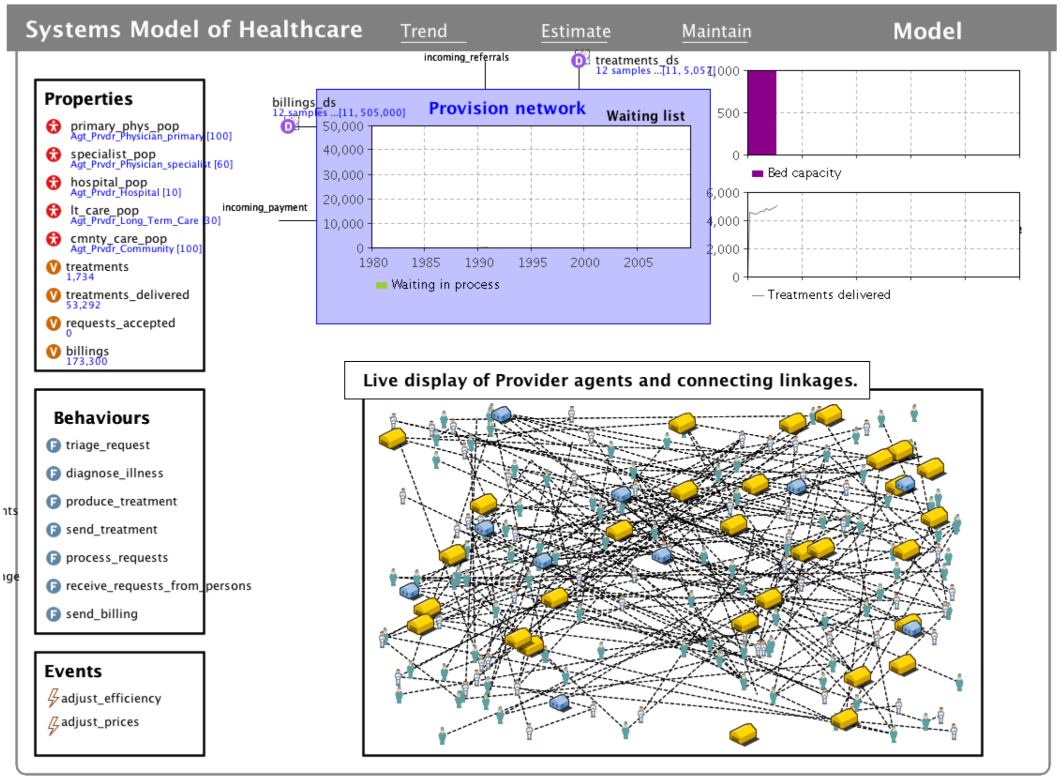


Figure 7.4: A second interior view within the simulation version displays key time trends in the Provision Network system (AnyLogic screen capture).

The Provision Network is also accessible from the main system as a distinct view. This view implements the environment and the agents of the Provision Network specification in subsection 6.4.2. Once again the view of this main systems includes time trend displays, groups of properties, behaviours and events, and an optional display of Network agents.

A window on the provider network indicators

The view of the Provision Network system shows in its primary display the time plot (blue panel) of the variable selected for inclusion as the essential indicator of Provision Network behaviour at the top level of the healthcare system. It also includes time series of other variables of interest (e.g., facility capacity and waiting time). When configuring a simulation experiment, these secondary time plots are individually interchangeable with the top-level plot.

Properties of the Provision Network system

The properties include collections (populations) of Provider agents of various types (primary care and specialist physicians, numbers of hospitals, community clinics and long-term care home). These are normally configured prior to running the simulation, but the magnitude and timing may also be specified and changed within predefined scenarios.

The properties also include variables that measure flows in (*requests_ accepted*) and out (*treatments*) of the network to and from the LifeCourse system, and exchanged with the Payment Exchange (*treatments_ delivered* and *billings*).

Behaviours in the Provision Network system

The behaviours are of two types. They include as before, functions that route flows in and out of the network (*triage_ requests*, *send_ treatment*, *send_ billing* and *process_funding*). As with the LifeCourse system, these functions allow the measurement of activity and performance at an aggregate level.

The second type of behaviours may be configured to implement the steps in Provider functions (*diagnose_ illness*, *produce_ treatment*) at an aggregate rather than an individual level. In this implementation, functions such as *triage_ request* may operate at a system level to allocate requests on a targeted basis – geographically, for example, where location of Person and Provider is relevant to an experiment, or where referral should be directed to a particular Provider. Coordination among Providers is implemented at the network level as part of the *send_ treatment* behaviour.

Events driving the Provision Network system

This version includes two events that may be configured to trigger modifications to prices (*adjust_ prices*) in market processes, and to production efficiency (*adjust_ efficiency*) in response to changing operating conditions during an experiment.

Extended measures and indicators of provision

This implementation repeats in its upper half the time plot (blue panel) of waiting list numbers shown earlier in the main display and secondary displays depict available capacity and waiting times as time trends.

Optional display of internal network activity

Once again, this view includes an optional display[3] to represent the connections in the network among the various Providers. In this case, the display

[3] The value of the optional display is transient in the extreme. It simply conveys a density of a communication network, and has no spatial significance.

shows Providers of various types (facilities as yellow buildings and individual physicians as green person icons), with dotted lines representing connections among them as configured at start up.

7.3.3 Payment Exchange system view

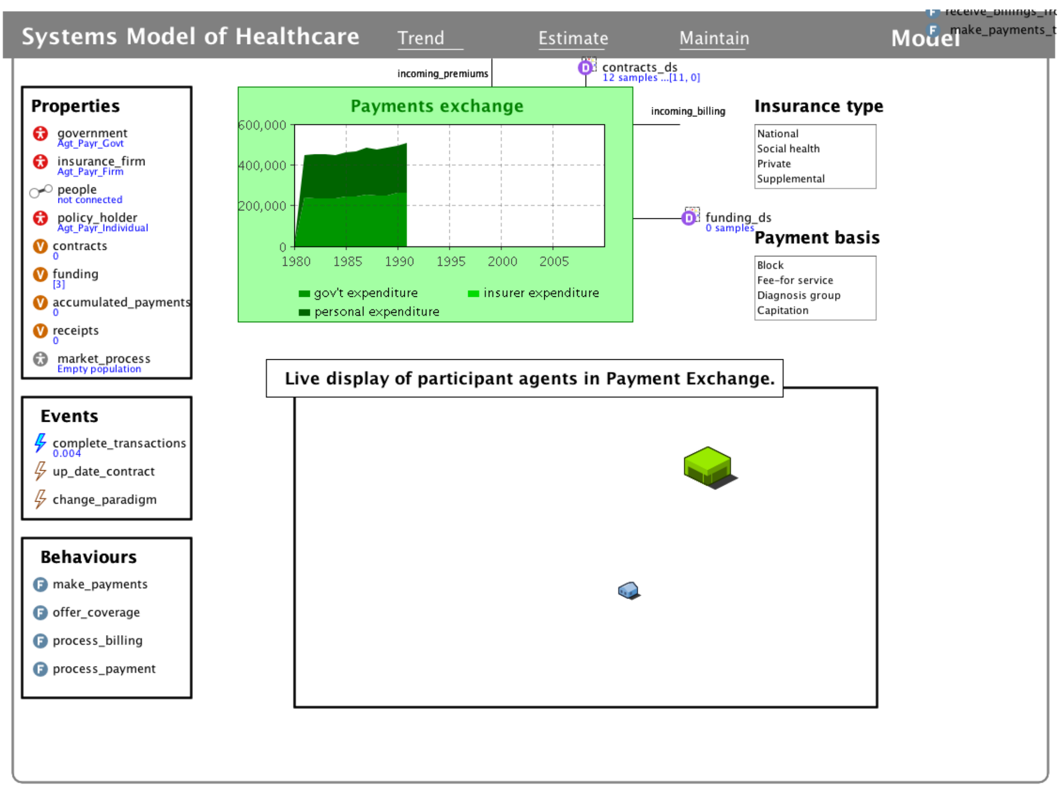


Figure 7.5: A third interior view within the simulation version displays key time trends in the Payment Exchange system (AnyLogic screen capture).

The Payment Exchange system agent implements the Payment Exchange behaviours environment and actors (subsection 6.4.3). In addition to the usual selection of displays, properties, behaviours and events, this view includes options to select insurance type and payment basis.

A window on the payment exchange

The view of the Payment Exchange system shows in its primary display the time plot (green panel) of the variable selected for inclusion as the essential indicator of Payment Exchange behaviour at the top level of the healthcare system. It also includes time series of other variables of interest (e.g., facility capacity and waiting time). When configuring a simulation experiment, these secondary time plots are individually interchangeable with the top-level plot.

Measures of Payment Exchange performance

As a prototype implementation, SMoH-s simulates only a limited set of the specifications in the ontology. Of relevance to the Payment Exchange network, the model includes only simple market transactions, and the display is limited to expenses by individuals and government.

Properties of the Payment Exchange

This prototype implementation limits the population of market agents to two participants – a Government agent, and one health insurance firm. For consistency in layout, these agents are depicted in the optional animation panel in the lower half of the view. More advanced configurations would include greater numbers of agent participants as appropriate to the chosen configuration.

The properties also include a pointer[4] to the same population of Persons also referenced in the Life Courses system.

Behaviours

The behaviours *pass through* the routing functions of individual agents similar to the design of the other main systems. These are complementary to the funding and payment behaviours already implemented in the LifeCourse and Provision Network systems.

Events

One event implements a simple market, triggering the behaviours that complete the funding transactions periodically. A second event updates Personal health insurance contracts, whether optional or mandatory, on a less frequent basis.

A third event, implementing a *change paradigm*, optionally changes both the payment basis and the insurance type to reflect a major change in policy in course of an experiment. Once again, this version does not implement the underlying function.

7.4 Agents in a healthcare simulation system

Agents are the main building blocks of SMoH-s. Whereas in the ontology version SysML specifies entities as *blocks* that are connected structurally and behaviourally, in the simulation version, those blocks and their relationships are mapped to analogous suitable of the chosen application platform. In the

[4]For technical reasons a different programming implementation and icon are used. This reflects the difference between *owns* and *uses* discussed in the SysML version. The behaviour of this property is effectively the same.

case of the AnyLogic platform, which is built around the Java programming language, the blocks of SysML are implemented as *classes*. Classes are best described as programmed modules that contain properties, activities and linkages to other modules. In AnyLogic, *Agents* are a special form of class that also includes connections to other agents and to the contexts in which those agents and connections occur. In keeping with the layering of themes and of systems in the other versions of SMoH, these Agents, as classes, may contain other Agents, implementing the ownership construct already used in SysML and in the ontology specification.

This construct (where agents contain other agents, and additionally may be special versions of more general types) is central to the simulation model. Even the SMoH-s version itself *is* an Agent. It implements the Person, Provider, Payer and Government actors (which were specified as *blocks* in the ontology version) as Agents, and encloses them in the top level SMoH-s agent. It represents the Life Course, Provision Network and Payment Exchange systems as complex Agents that are also contained in the SMoH-s Agent. Depending on their specifications they are associated[5] with collections – groups or populations – of the various actors. In summary, the model is a hierarchy of Agents – a *system of systems*.

7.4.1 Person implemented as an agent

The Person agent (Figure 7.6) implements the specification discussed in Figure 6.9 in the ontologic theme. It has properties that correspond to the values of the SysML block, and functions that implement the block's activities.

The software implementation enables further exploration of the running model at a level in the model below the Life Course system. In this instance, details of an individual Person agent may be viewed.

Properties of a Person agent

The properties of Persons (specified in subsection 6.3.2 and represented in the upper left space of the Person view) include essential demographic parameters, *age*, *sex*, an estimate of *life expectancy*, and categorical measures of socio-economic status and of insurance *coverage*. Crucially, the agent includes an index of the *wellness* property. The value of this indictor is set at 100 by default and is reduced below that value for the duration of an episode of illness.

The implementation here, as a prototype, uses only minimal variation in parameter values, although the underlying design allows for modification in

[5] It is necessary to distinguish *association* from *containment* to avoid ambiguity in coding. The effect on system functioning is the same.

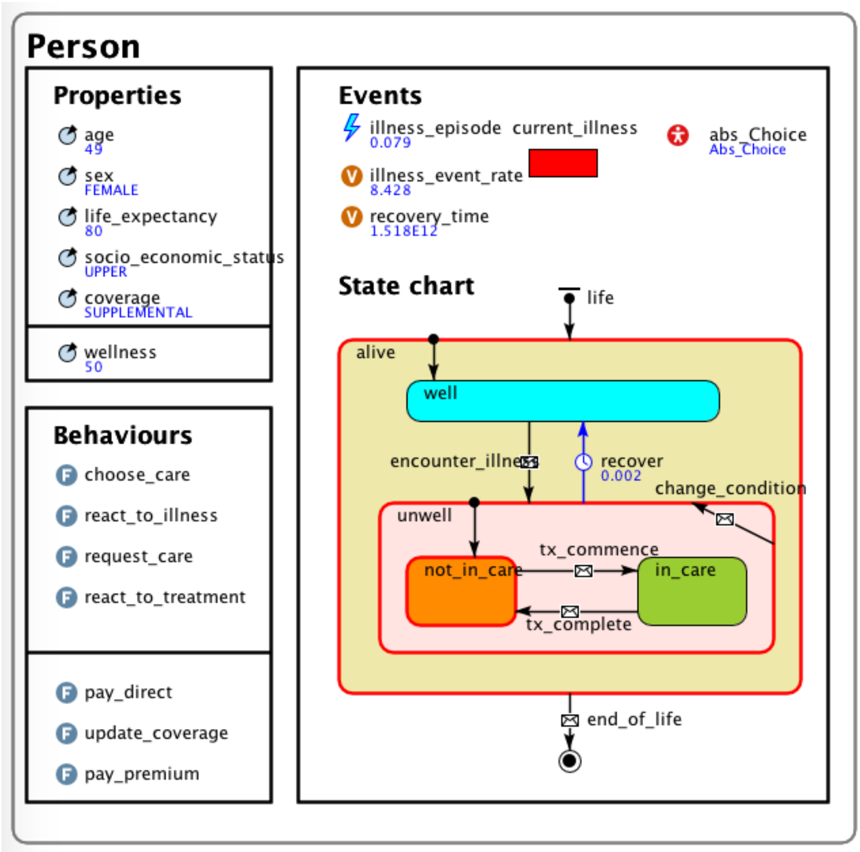


Figure 7.6: The properties, behaviours, events and state may be visualized during a simulation (AnyLogic screen capture).

later versions. For example, the estimate of *life expectancy* is assigned when an instance of the Person agent is created, interpreted as birth in the simulation. In this implementation, the assigned value is used to trigger the *end of life* event. However, a future version would include refined behaviour to modify the estimated life expectancy in reaction to an episode of illness. Similarly, the constraints specified in the ontology are implemented here a simple threshold function within a simple Java class module. Future implementations could refine this class with more sophisticated function based on game theory constructs.

An illness indicator (a red rectangular icon in the upper right region of the view) signals that an illness episode is currently active. An abstract *choice* agent in the Person is activated on when the occurrence event in the Life Courses system triggers an illness. These conditions are represented in greater detail in the State chart.

State chart

The view in Figure 7.6 of the Person agent replicates graphically and in code the state chart that was previously specified in the ontology model (subsection 6.3.2). A Person agent resides usually in the *well* state, but when an illness is encountered, the *wellness* parameter drops below a threshold level, and the agent moves to an *unwell* state, and by default to the *not_ in_ care* substate. The behaviour *choose_ care* activates an abstract *choose* agent that determines, based on the Person's properties and wellness, if a request for care will be made.

The state chart signals the current state of the Person during simulation. In Figure 7.6, for example, the red borders in the state chart indicate that the agent is in the *unwell* and *not in care* states.

Illness occurence

The occurrence of an illness is implemented as an event in the environment of the Life Courses system. This event triggers the transient creation of an Illness agent within the Person agent (shown as *current_ illness* in Figure 7.6). A function in this new agent acts on the *wellness* property, triggering a transition in the Person's state.

In this version of SMoH, the transitions between states expose an fundamental, essential, distinguishing feature of healthcare as a system: the transitions are triggered, not by the Person agent within the LifeCourse system, but by a Provider in the Provision Network system. In Figure 7.6, the *envelope* icon on both the *tx_ commence* and the *tx_ complete* linkages signify the a Provider agent has executed one of its behaviours. The following section describing the Provider agent view resume this discussion.

Events affecting the Person

As specified previously in subsection 7.3.1, the primary event that affects the Person agent is the occurrence of an illness episode. Figure 7.6 depicts an agent that recently encountered such an episode. These are specified as stochastic events in this version, at a frequency specified as a Poisson distribution, and with a characteristic, normally distributed duration, termed *recovery_ time*.

Requesting care behaviour

Certain agent *behaviours* implement, as functions, the activities and conditions that produce changes in the Person's state, from *well* to *unwell*, and from *not in care* to *receiving care*. The *request_ care* behaviour, however is crucial to the connections among the Life Course and the Provision Network agents. That function embeds a number of internal functions to generate a special data structure (a *package*, addressed below) which the Person agent then *sends* as a *message* to the Provision Network, where that high level agent handles it.

The sending programming pattern is repeated in other parts of the model and is central to the model's representation of healthcare as a whole system.

Choice behaviours

Each Person agent implements the following default choice: when Illness occurs, it sends a request to the Provision Network. The higher level Life Courses system aggregates that measure as time trend averaged across all Persons.

In this implementation, the decision process is not contingent on coverage status. However, that property is included property of the Person agent. Future implementations of the simulation could include configurations of the Person in which requests would be only when coverage exists. This would allow a measure of a hidden state in which a need would exist but would not met within the system.

7.4.2 Provider agent

The generic Provider agent implement a series of processes, representing the activities of the Provider block in functions, and with a link to other providers.

Each of the provider types is represented as an agent that specializes the generic Provider. Figure 7.7 depicts a Hospital Provider, which in this model produces days of bed occupancy and is constrained to a maximum capacity in a one day period.

The mechanisms in the specifications are implemented in the pattern of a discrete event process similar to those referenced in reviewing existing models. Each process element in the sequence corresponds to an activity in Figure 6.5 in the ontology specification.

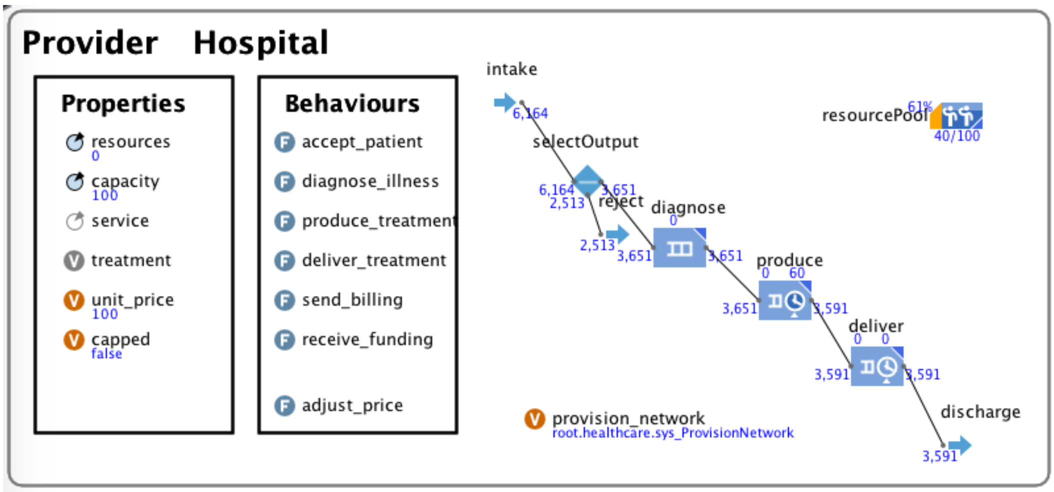


Figure 7.7: The Hospital Provider agent implements its activities as a Discrete Event process (AnyLogic screen capture).

Intake

The process of provision begins whenthe Provider agent *receives* at the intake a request message from a Person agent. The message package contains information about the Person requesting, including her insurance status. This is sufficient, in this simple model, to accept or reject the request. A function implements this step as a simple binary choice.

Diagnosis

The next step implements a simple queue, representing a waiting list. Priority assignment is available, but that functionality is not used here. The Request remains in the queue until resources are available to complete the remainder of the steps. In this model, the *diagnosis* function simply passes the Request through to the next stage.

Production

The *produce* step implements a simple production function, allocating a fixed amount of funds from the resource pool, based on the unit price of the treatment required and on the number of units. In the case of a Hospital Provider, the fixed amount corresponds to the cost of providing a number of inpatient bed days. In this model, the amount is fixed at a nominal level. Production (allocation) continues until the capacity of the resource pool has been reached for the current period.

Delivery

In the final step of the process, and using a software pattern similar to that used previously by the Person agent, the Provider generates a *treatment package* and *sends* this package as a new message to the sending Person agent. This completes the process, and the Request is archived within the model.

In this implementation, *discharge* is immediate following delivery of care. More advanced implementations will connect this step with the need for and availability of other treatments downstream.

7.4.3 Payer agent (e.g., insurance firm)

The Payer agent implements the specifications as properties and behaviours in the ontology model (subsection 6.3.4).

Provider compensation

Primary behaviours of the Payer agent relate to information received in the form of billings from Providers (accounting for services provided to Persons)

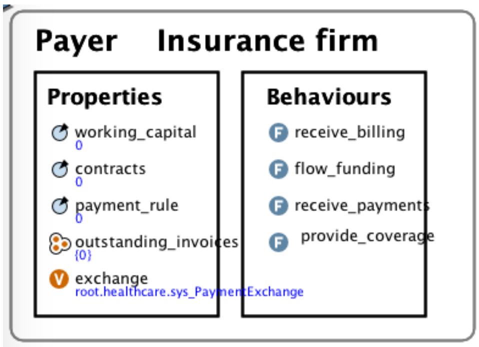


Figure 7.8: The Insurance firm Payer agent implements functions that calculate Payments and send them as Flows (AnyLogic screen capture).

and for funds returned to Providers as compensation for those services. The exchanges between agents once again use the patterns of sending and receiving *packages* and *messages*. These are information and payment packages in the case of payer agents.

Each payer has a Payment rule implementing an algorithm that determines funding to a Provider based on billings received. Other properties track the movement of funds into and out of the agents resources.

Each Payer agent retains a record of all payments for aggregation at higher levels of the system as an indicator of total cost.

INSURANCE CONTRACTS

When the model configuration permits the sale of individual health insurance contracts, the payer agent also receives periodic payments from individual Persons, and send coverage in the form of information packages. In this model, both government and the insurance firm provide insurance coverage, using a simple algorithm[6] that pays the full cost of treatment.

7.4.4 Illness agent

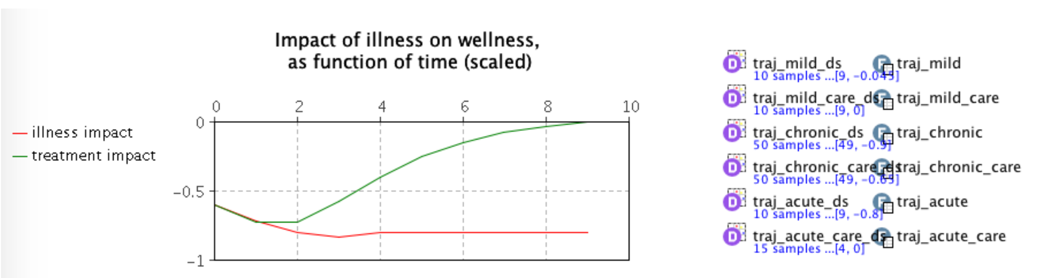


Figure 7.9: Two trajectories are coded for illnesses (AnyLogic screen capture).

[6]Payment is calculated on a fixed rate per treatment provided, and transmitted monthly.

When a Person generates an illness agent, it assigns itself two time trends that implement trajectories of impact on the Person's wellness throughout the illness, including while in treatment if that is relevant. These trajectories, illustrated in Figure 7.9, are generated within the active model for demonstration purposes only; they are not applied to the Person's wellness in the course of the simulation.

7.4.5 Flow as classes or agents

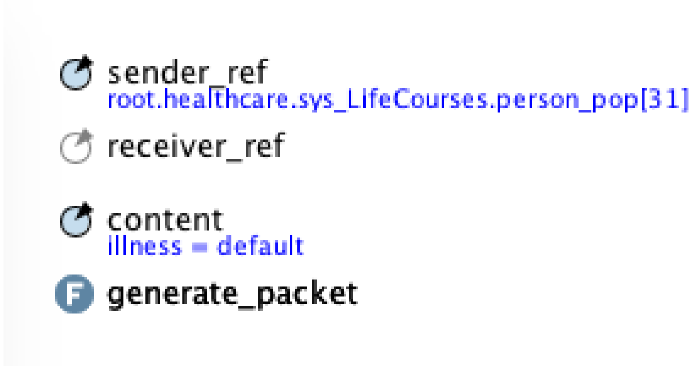


Figure 7.10: Flows are implemented as data structures that include sending and receiving agents and a packet customized to the type of flow (AnyLogic screen capture).

The implementation of Person, Provider and Payer agents include references to *messages*. The mechanisms for sending and receiving these messages (see Figure 7.10) are embedded in the programming structures of the simulation platform. An agent initiating the message may direct the data package to an identified agent in another group, or it may allow the message to be directed at random. This is particularly useful in the simulation of some healthcare systems, where requests may be directed to a particular individual, or alternatively to anyone who is available.

Flows are implemented as a special type of Agent that can be *sent* and *received* by agents in the model. The generalized *Flow* agent has placeholders for the agents involved – including a default null value for the receiving agent to permit routing of the message to an agent chosen at random.

Separate types of *flow* are distinguished by their *packets*. Packets may be specified as agents if necessary; in this model they are implemented as texts only.

Every message identifies the sending agent, the receiving agent, optionally, and a specification of its content. The content is contained in a package (Figure 7.11) as one of five available types, for submission of *billing*, delivery

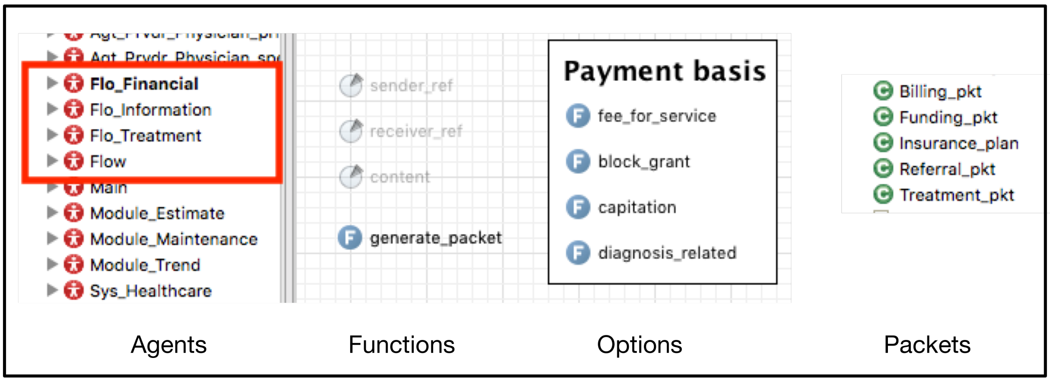


Figure 7.11: Specialized flow agents are distinguished by the data embedded in their packages (AnyLogic screen capture).

of *funding*, providing an individual health *insurance* contract, requesting a medical *referral* and providing *treatment*.

Exchanges between Persons and Providers are conducted using a *referral* packet, which may include details of symptoms, and other administrative details. This packet is also used when Providers exchange patient information in the course of clinical referrals.

Treatments produced by Providers are delivered through packages that reference the details of the *treatment*. These details are interpreted by the Person in the reaction to care.

The mechanisms of the payment exchange are implemented using *billing* packets to report clinical activity, and *funding* packets as payments flowing back to the providers.

Details of insurance coverage are provided within an *insurance* plan packet.

7.4.6 System constraints as agents

In this type of simulation, the meaning of *agent* extends beyond the anthropomorphic interpretation of the word in social contexts, beyond the representation of human actors. Here, an agent is any entity that has properties and performs actions[7]. The approach used in this model extends and includes in particular the capacity to represent as abstractions the constraints specified in the ontology model. These constraints may express complex formalisms in the relationships between the properties of other objects. The benefits of using constraints are realized in particular when those relationships are non-linear, and more significantly, where the relationships may change and adapt in reaction to events.

In this model, most of the relationships have been expressed a simple linear functions that are, at most, bounded by limited capacity or resources. Sim-

[7]Recall the latin root of *agire*, to act.

ilarly, choice mechanisms have been implemented as binary, determined only by fixed thresholds. In future versions, they may be implemented as adaptive agents implementing higher order algorithms in their functions.

However, the structure of the simulation version allows for the implementation of the choice mechanisms as an agent type with the functional capacity to implement more sophisticated decision algorithms such as those found in models of game theory. Similarly, the *illness agent*, again an abstraction specified as properties and functions, has the capacity to modify its impact on wellness over time. Different versions of the illness agent can be specialized to address the impact of various categories of illness, distinguishing, for instance, acute and chronic classifications. Agents representing these constraints are included in the model, but have not been implemented in the scenarios.

7.5 SMoH-s - an experimental laboratory of agents and scenarios

While each of three versions of SMoH is interpreted to represent healthcare systems in the real world, the simulation style of SMoH-s is intentionally designed to encourage and support experimentation.

7.5.1 User views

The model is accessible by users at every level of the system. The top level displays an indicator for each of the essential perspectives. The controls for running, pausing and stopping a simulation reside at this level along with the available parameters that configure the representation to a target system. The inner levels of the major systems display additional indicators and provide access to selected agents at an individual level. The simulation is available on the internet and on the desktop. While the cloud version benefits from increased processing power, its interactive capabilities are currently more limited.

7.5.2 Configuration of the SMoH-s: The case of the Netherlands

Every parameter in the model has a default value by design. In specific experiments, these values may be redefined to meet the requirements of a particular experimental design. In the example experiment reported below, the healthcare model is configured to represent the healthcare system in the Netherlands over a thirty year period, and to respond to regulatory interventions that affect budget allocations and configuration of health insurance at the level of individual people. This experiment was chosen both because comparative historical data is reported in the literature (Helderman *et al.*, 2005; van Ginneken, 2015), and because the policy decisions are readily configured as scenarios in the prototype simulation application.

The experiment explores the questions *what if budgets are capped?*, *what if health insurance is mandated* as universal and provided by the commercial market? These questions reflect generic considerations that faced the participants in the healthcare system in the Netherlands. Governments at some time must address questions of access to and affordability of healthcare services. Public funding of healthcare mitigates the personal financial risks associated with illness and injury, either by funding care directly, or by underwriting health insurance plans. However the expenditures add to budgetary pressures and may need to be managed and limited. Other considerations apply to the design of the insurance schemes themselves. Since the economics of insurance funding depend in part on broad sharing of risk, it may be necessary to mandate participation by everyone, regardless of individual risk. Furthermore, if administration of insurance coverage is placed among commercial firms, the rules of that market must allow both for returns on investment for those firms and favour fair competition.

In this simulation, the external context is set by a few demographic, clinical and economic parameters. A starting population is specified for 1980, and annual birth and mortality rates assumed constant for each subsequent year. The economy as measured by GDP is assumed to grow at a constant rate.

Values of most internal parameters of the various systems remain at their default levels.

The model is tested in a limited configuration against some historical trends that are not readily represented by existing models. Its explanations are compared to observed outcomes that have been reported in the Netherlands healthcare system over a thirty year period. Between 1980 and 2010, the policies and structures of that healthcare system changed in three recognizable phases in response to emerging trends. The generic model, configured to minimal parameters previously observed in the real world system, was run using three scenarios representing the policy interventions. The scenarios proceeded incrementally, each extending the previous one. This provided synthetic counterfactuals that attempted to demonstrate how timed interventions averted potential problems, and exposed the causal outcome of the respective policy changes. The predicted outcomes generated by the model in these scenarios compare favourably if modestly to the observed historical outcomes.

The simulation was configured to represent the structures of the healthcare system in the Netherland to explore several scenarios that represent the outcomes of two *what if* questions. The first asks *what if the existing payment on* *demand rules were modified to restrict the rate of total expenditure?*. The question relates to a pattern of increasing expenditure observed over the decades since the healthcare system was formally organized. The phenomenon was particularly evident in the decade beginning in 1980, and by 1990, the fraction of government spending consumed by healthcare funding caused concern.

The second asks *what if the current partial health insurance schemes were rationalized and extended to the whole population?* This relates to the introduction of mandatory health insurance in the first decade of the the twenty-first century. This substantial change in public policy was first contemplated two decades earlier, but was due aside due both to logistical obstacles (lack of information information and communication infrastructure) and to purely political exigencies (changing ideological positions of a newly elected government).

Several reviews of reform of the Dutch healthcare system have noted interventions aimed at improving various outcomes by controlling cost directly and through market reform (Bevan and van de Ven, 2010; Enthoven and van de Ven, 2007; Okma and de Roo, 2009; Schut and van de Ven, 2005; van Ginneken *et al.*, 2013; Vrangbaek *et al.*, 2012). The history of healthcare reform in the Netherlands is also documented in the Health system in Transition series of reports, (Schäfer *et al.*, 2010), revised and updated in (Kroneman *et al.*, 2016). Two studies in particular (Helderman *et al.*, 2005; van Ginneken, 2015) provide insights in the mechanisms of those reforms - the pressures leading to and the consequences of policy intervention. Their findings provide empirical, qualitative observations against which the model's predictions are compared in assessing its validity.

Model explanations in three scenarios

The goal of the simulation is to represent coarse-grained changes in system variables that correspond to the outcomes reported in the narrative of (Helderman *et al.*, 2005; van Ginneken, 2015)

The model is configured to represent constant and variable parameters and indicators representing the healthcare system of the Netherlands. Every scenario run begins at the beginning of model year 1980 and continues for 30 simulated years.

The parameter settings in Table 7.1 are constant[8] in all scenarios.

Background conditions

Systems of support for healthcare provision in the Netherlands had their origins in the late nineteenth century, but the foundations of a national system

[8]Parameters specified as *approximate* are distributed normally about the the indicated value.

Table 7.1: Configuration of constant properties

Parameter	value	notes
System wide		
Population (1980)	10,000,000	(scaled 1:100 in the model)
Birth rate	9.5 per 1,000	
Death rate	8.0 per 1,000	
Providers	one	diversity not specified
Payer	one	diversity not specified
Government	one	
Person		
Socio-econ status	LOWER or UPPER	adjustable ratio
Illness types	Only one	Incidence rate variable
Illness Impact	reduce wellness	standard recovery rate
Treatment impact	recovery rate doubled	
Provider		
Capacity	variable # beds	while funds available
Admission	if insured	if insurance coverage
Treatment	5 bed days	
Report	monthly	
Payer		
Payment	monthly	regulated
Coverage	yearly	at prevailing price
Update	yearly	funding rate and premium rate

were laid only in the 1940s when government regulation set standards for the provision of insurance. The system followed the Bismarck template of *sickness funds*. In general, insurance was tied to employment, and to a single insurer in a given region. It was supported by statutory contributions from wages for employees earning up to a certain income level. Supplemental insurance was provided to others who wished to avail of coverage. Special funds were created for those whose means did not afford those opportunities.

Crucially, providers were paid retrospectively for services provided; demand was met with supply, at the discretion of the provider – formally in the judgment of the physician. It was driven by the requests and needs of the individual members of the population. Those needs inevitably increased with growth in the population typical of the post-war period, even with relatively constant incidence of common illnesses. In the retrospective payment environment, overall expenditure rose, both in real and in constant dollars. By 1980, which is roughly when inter-country comparative data is available in OECD datasets, expenditure on health had reached 8.5% of GDP, and was growing at an average rate of roughly 0.5% per year. This year marks the beginning of the comparison period 1980–2010.

Scenario 1: Initial expansion with system growth

The first *baseline* scenario establishes estimates of trends in system indicators over the period of the simulation (30 years). This scenario allows endogenous mechanisms to operate, but is free of deliberate interventions, forming one limb of the counterfactuals that support explanations of the effect of such interventions. Within the model, changes in the population census due to births and deaths cause corresponding changes in the volume of care requested from the provision network. In the initial state of the model, this demand is moderated by the fraction of individuals who are not covered by health insurance.

This baseline scenario reflects the underlying mechanisms of the system in its original form. It represents the continuing behaviours of that system from 1940 through 1980 and as it might have evolved unconstrained up to 2010. The model is configured as follows:

Table 7.2: Configuration for scenario 1: 1980 - 2010

Parameter	value	notes
Person		
Insurance	covered	LOWER socio economic status and UPPER if supplemental
Provider		
Response	immediate	all treatments reported
Payer		
Payment	per treatment	price fixed by government

Model predictions for scenario 1

The screen view in Figure 7.12 shows the selected scenario as *1980 - base scenario* in the *Healthcare system context* panel in the upper left panel.

The *Census* display (top left) again in the same context panel shows the growth in population. The numbers of people with various types of insurance coverage are displayed in the LifeCourse panel in the upper right quadrant. The blue *referrals* depicting the flow to the Provision Network (blue panel in the lower right quadrant) indicates that referrals increase over the entire period simulated, and the *treatments* flowing back from the Provision Network increase at the same time. Since there are no restrictions on the volumes of treatments, the Provision Network panel shows that there are no waiting lists.

Billings proportional to those treatments are seen in the flow panel connecting the Provision Network to the Payment Exchange (green panel, lower left quadrant), where indicators of personal and government expenditure in-

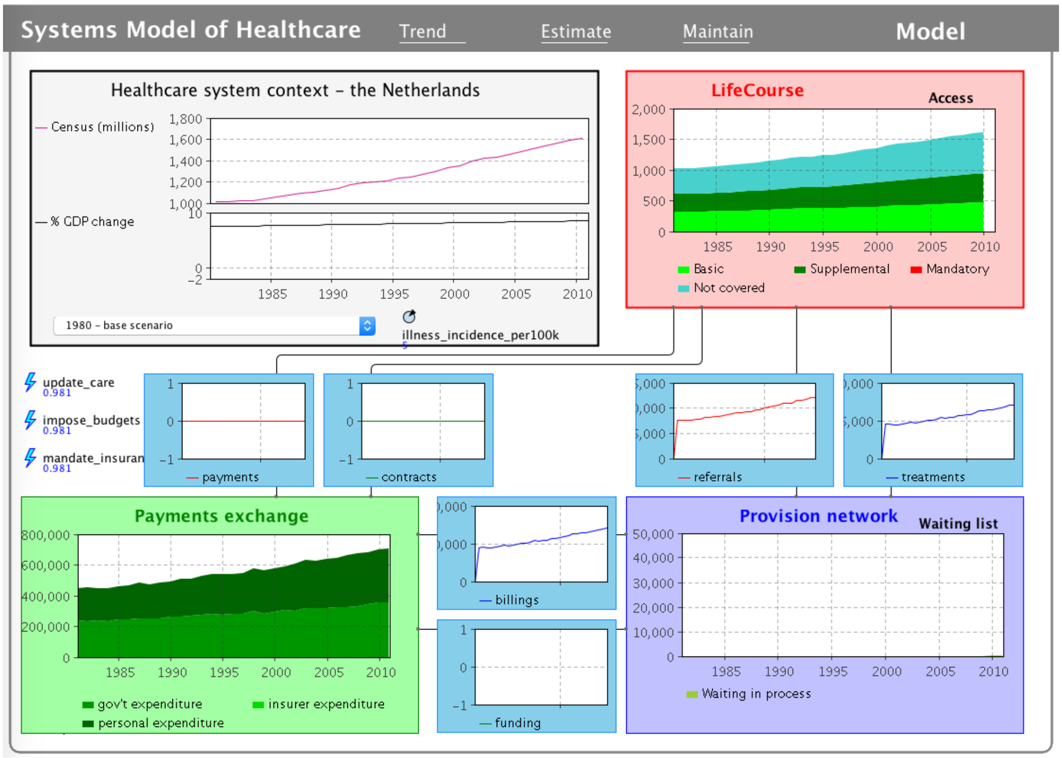


Figure 7.12: In the baseline scenario expenditures grow under retrospective payment (AnyLogic screen capture).

crease again in the same proportion. On a national scale this may be offset by an overall increase in GDP and expenditure on healthcare as a portion of GDP may not rise at the same rate. Nevertheless, the model predicts a constant increase in healthcare expenditures that without intervention will by 2000 account for approximately 10% of GDP, an fraction of overall consumption considered unacceptably high by the Netherlands government at that time.

Budgetary Control 1980 - 2005

For four decades, the sickness funds had managed the supply and pricing of insurance for the majority of the population, with little oversight nor intervention by the state. However, by the early 1980s, concern had grown with the steady increases in the costs of healthcare, and with the consequent impact on the economy. The government of the time (i.e., 1980) began to intervene to exercise greater control of the system. This took the form of budget limits imposed on the providers (mostly hospitals) and caps on services for which insurance coverage could be provided by the sickness funds under the statutory health insurance provided for employees earning below a given wage. Both of these measures placed limits on the services that could be provided. Although one of the organizational responses to the budgetary pressures was to direct greater attention to process improvement[9], the major impact was on volume of services available and provided. Services were no longer available when requested, and waiting times and waiting lists grew.

Scenario 2: Budgetary control of expansion

This scenario extends the previous one, which was considered as a baseline counterfactual to the intervention in model year 1990. The main modification is in the exogenous modification of Payer mechanisms and the consequent changes in Provider response. The model is configured as shown in Table 7.3:

Table 7.3: Configuration for budget control scenario 2: 1980 - 1990 - 2010

Parameter	value	notes
Payer		
Payment	capped	fixed amount every period Beginning 1990
Provider		
Capacity	fixed by funding	
Requests	up to available capacity	excess added to witting list

Model predictions for scenario 2

The screen view in Figure 7.13 shows the selected scenario as *1990 - state control with capped budgets* in the *Healthcare system context* panel in the upper left panel. The population grows as before (shown in the Census panel). Insurance schemes have not changed in this scenario, the pink LifeCourse panel continues to show the numbers of people with the various types of coverage and the predicted flow of referrals to the Provision Network remains as in scenario 1.

Although this scenario does not change the process of retrospective payment for services, the providers respond by limiting production to the capped resources available. The panel displaying flow of *treatment* connecting the Provision Network to the LifeCourse system shows that treatment level off in 1990 at a constant value to a rate that can be produced within the constrained funding. *Referrals* for treatments within a given period are honoured up to the limit of available (funded) capacity and the remainder deferred to a later period.

This leads to waiting lists in the model that represent the known phenomenon in real world healthcare. This is seen in the Provision Network

[9]This was at a time when Total Quality Management (TQM) in its various flavours was widely embraced by many sectors including healthcare efforts to improve productivity. Success varied widely.

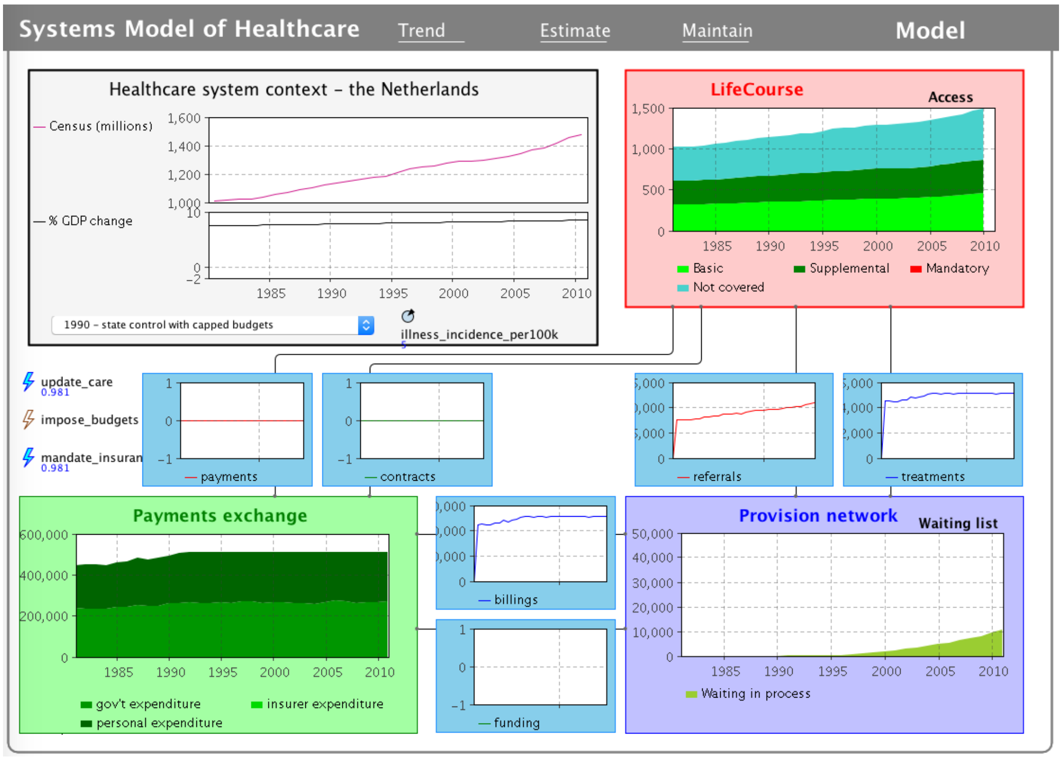


Figure 7.13: With budgets capped, waiting times grow (AnyLogic screen capture).

panel, where the number of people awaiting care increases from zero beginning in 1990. This is matched by a levelling of expenditures in the green Payment Exchange panel.

Note that the structures of the artificial model allow examination of not only the count of persons who are waiting but also the distribution of elapsed waiting time for these people. This is an instance in which the synthetic experimental environment is superior to the real world environment that is constrained by low quality and availability of data.

The model predicts that the intervention by the government effectively constrains problematic expenditure growth, but as a consequence produces the unwanted side effect of delaying care for some people. Furthermore, the severity of the delays in terms of numbers and duration grows over time.

Market and universal insurance 2005 - present

In the late 1980s, a special task force (Okma and de Roo, 2009) studied the healthcare system, recommending a radical redesign to reverse inequalities of access and to manage costs more effectively. The Dekker report proposed that the structure of the health insurance be altered to allow people to choose among insurers, and to require that all people carry a basic health insurance policy. The underlying principles were to allow market forces to operate in controlling the cost of insurance (and hence of healthcare) and to maintain a large risk pool for competing insurance carriers.

The government of the day introduced legislation to enact these changes in 1995. The legislation failed to pass, not, it appears, because it lacked merit but because its implementation required heavy commitment to new information and coordination infrastructure.

With a change in government after the turn of the century, similar legislation was introduced and passed into law in 2005. In contrast to the failed initiative a decade earlier, this move succeeded in large part because gradual improvements that had been implemented[10] enabled the heavier information exchanges required to manage the competitive markets.

Trends in several indicators changed in direction and magnitude with this reform. As expected, basic health insurance coverage rose close to 100%, and supplementary private insurance fell markedly. Expenditures rose sharply. Aggregate data on waiting lists and times are available for this period, but in the absence of reported data for the earlier periods, routine changes in those indicators are not observed.

Table 7.4: Configuration for budget controlled scenario 1980 - 1990 - 2005 - 2010

Parameter	value	notes
Person		
Insurance	all	beginning 2006
Provider		
Price	reduced 2%	assumes productivity improvement to remain competitive
Response	Immediate	within immediate funded capacity
Report	all persons	
Payer		
Payment	at updated price	subset of reported treatments Beginning 2006

Scenario 3: expansion then control then universal insurance, market

Additional interventions represent in simplified form the managed market reforms implemented by agreement among the political and commercial participants in the healthcare system. For this scenario, Table 7.4 shows how the model elements are configured in 2006.

[10]Recall that this period included the rapid adoption and expansion of network technologies across most industries and sectors.

Model predictions for scenario 3

The screen view in Figure 7.14 shows the selected scenario as *2006 - universal health insurance/market mechanism(s)* in the *Healthcare system context* panel in the upper left panel. The population grows as before.

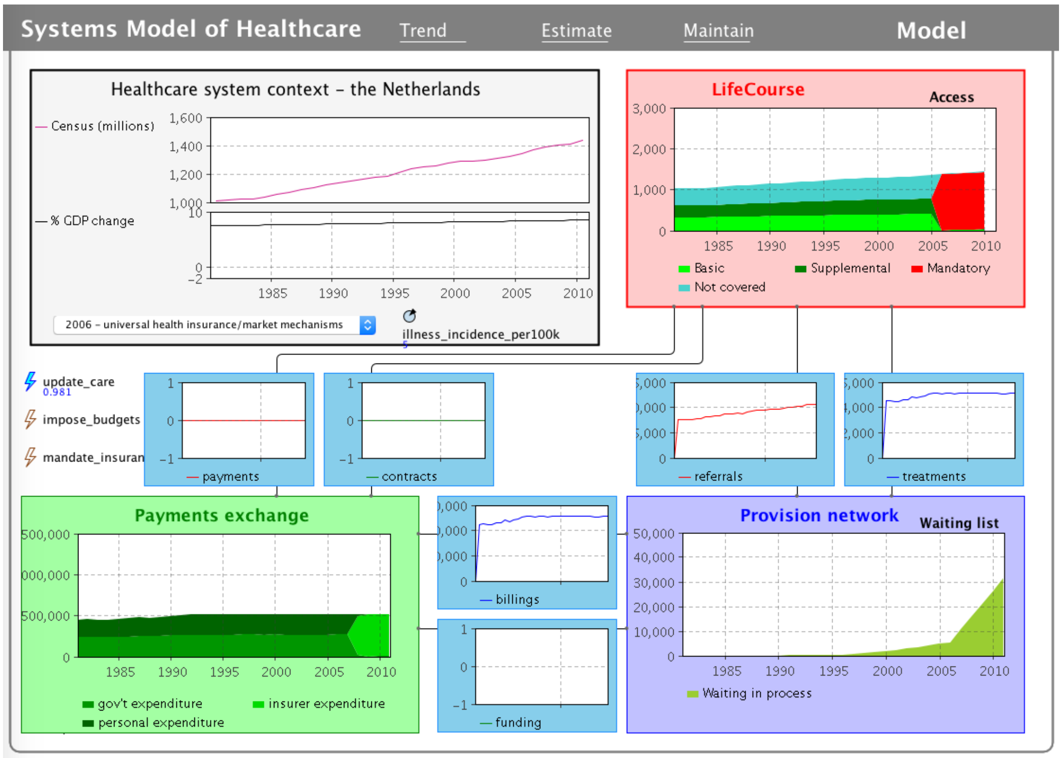


Figure 7.14: Expenditures stabilize under managed competition (AnyLogic screen capture).

The outcomes of this scenario displayed in Figure 7.14 show the effect of implementing mandatory insurance in 2005. Insurance schemes have now changed in this scenario, the pink LifeCourse panel shows a substantial change in insurance coverage coincident with the introduction of universal (mandatory) insurance in 2006. The trends show that the profile of insured individuals changes, with the elimination of the original basis statutory insurance for all people in the lower socio-economic groups, and of the fraction of the upper socio-economic group who elected to obtain supplemental insurance privately and voluntarily. Everyone in the population is covered from 2005 onwards.

The introduction of coverage to persons previously uninsured affects their response to illness, and the frequency of referrals increase markedly in 2006, as shown[11] in the flow panel connecting LifeCourse and the Provision Network. The volume of treatments flowing from the Provision Network to the LifeCourse continues to be capped by funding, and in the face of increased

[11] Admittedly the effect is difficult to observe in this static view since it occurs at a small scale and for the small time period at the end of the time axis.

rates of referral, the number of persons waiting for treatment increases at a greater rate, as shown in the blue Provision Network panel.

The green Payment Exchange panel shows that the magnitude of health expenditures remains the same. However the sources of funding change, with the introduction of the managed market for health insurance; flows that had previously flowed either through government supported statutory insurance or through private plans are replaced with funding through the competitive market of insurance firms. This simulation does not model any cost reductions resulting from efficiencies associated with a competitive marketplace for health insurance, because at this stage, the model includes only the exchanges of funds on the basis of nominal costs.

As a consequence of universal health insurance, demand is seen to increase, largely from the portion of the population in the upper socioeconomic groups who previously choose not to purchase insurance. This scenario runs for only a brief period beyond the introduction of the latest policy. The effects of competition on cost reduction have not been reported in the literature for that period.

7.6 Summary of the prototype simulation model

In this version, built with and around software modules, the linear treatment does not do justice to the *gestalt* of an interactive computer based simulation. The functional and hierarchical relationships among the agents are embedded in the programming code of their functions. The order in which the mechanisms and agents are presented here is arbitrary. The interplay among them may be described once they are listed, but their essential, explanatory relationships are more fully appreciated through interactive exploration and experimentation in the software application created by the author.

SMoH-s completes the pathway of styles from the expert evidence in the healthcare literature to the exploratory environment of planners and practitioners as proposed answers to the questions guiding this research. Through the phased approach of three versions of the healthcare system model, it retains the links to the observed real world of healthcare that supports its soundness as a model. But because it also inherits the limitations of its precursor versions, its boundaries are relevant to its application as a practical instrument to support healthcare reform. The following chapter reviews the model in its entirety, assessing how well it answers the questions originally posed in chapter 2.

7.7 Chapter summary

This chapter implements the previously specified systems model as a computer simulation. Using AnyLogic as a software application, the simulation version of the model – SMoH-s - is represented as an assembly of agents, first at the top level, and then as inner layers. The model displays the relevant properties of these layers as they behave and interact over time. This prototype simulation version of healthcare serves as an experimental laboratory in which to investigate outcomes of strategic choices.

Part III: What Have We Learned?

Assessment: How does the SMoH model answer the research questions?

This chapter closes the research loop, by assessing the findings in the previous three chapters as answers to the research questions set out in chapter 2. The first three sections address each of the questions in turn. The limitations exposed by these assessments are consolidated and restated as boundary conditions here in the final section.

8.1 SMoH as an application of model theory

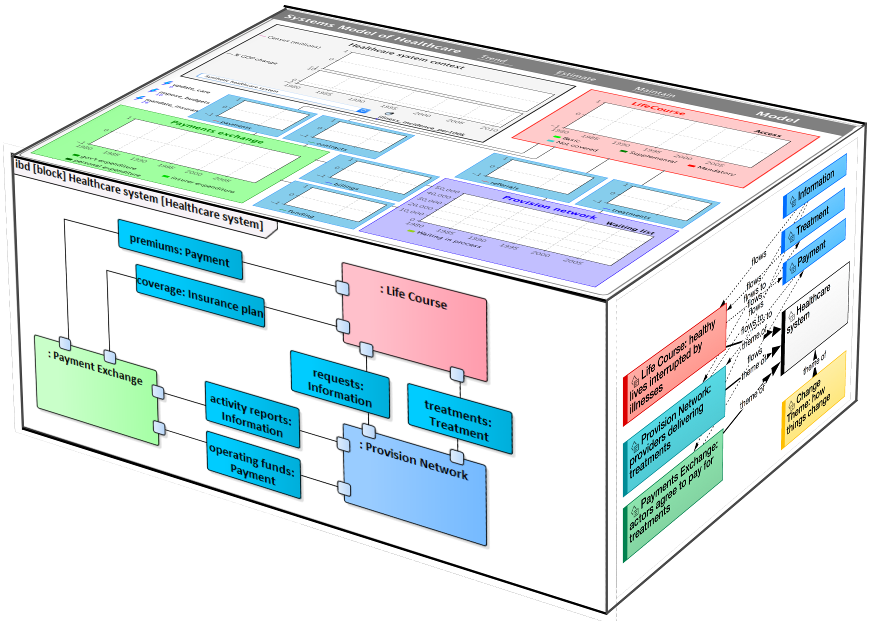


Figure 8.1: Each version of SMoH provides a different interpretation of the systems representation at the core of the model (AnyLogic screen capture).

The previous three chapters described SMoH, how the model was developed using empirical data from the expert literature to discover themes, translating the themes as specifications in a structured language of systems, and then exposing those specifications interactively in a software simulation. Each iteration has been intentionally identified not as a new model, but as a particular version of a core model, each one serving a particular purpose.

The complementary relationships between the three versions are reflected in Figure 8.1 as distinct interpretations of the same representation at the core of SMoH.

Recall that methodology based the experimental and the operational design of SMoH on the DEKI account of scientific models developed by Frigg and Nguyen (2017b) and reviewed in the literature of model theory. Summarizing that account:

- A *scientific model* uses the interpretation of an *object* as a *representation* of a *target*.
- The representation is of the target is limited to certain properties as *exemplifications* that are thought to be relevant in portraying the target.
- These exemplifications are chosen to realize the *epistemic* purposes of the model.
- A *simulation* is a dynamic model and hence includes *events*.
- Where the epistemic purpose includes explanation, the exemplifications and hence the interpretation of the the *object* should include *mechanisms* (i.e., entities and activities that produce results) that are *causal* (i.e., with counterfactual dependencies).

The main departure in SMoH from the original account is in using three related objects whose interpretations link together to form a cognitive pathway from narrative description to an interactive experimental environment.

Table 8.1 shows how these features of the model account are realized in the Systems Model of Healthcare.

8.2 Three claims

From the outset, the goal of this research has been to build a model that can explain how healthcare works *as a system.* In chapter 2, three questions frame this goal as:

- a design question asking how to construct a suitable model of healthcare,
- a theoretic question asking how healthcare works as a system, and
- an evaluative question asking how well the systems model of healthcare works when asked to explain real-world phenomena.

Table 8.1: SMoH Implementation of model features

	Model Feature	SMoH Implementation
1.	Denotes as target	Generic healthcare system
2.	Representation-as	Dynamic causal system
3.	Epistemic purpose	Understand (SMoH-t) Explain (SMoH-o) Experiment (SMoH-s)
4.	Exemplifications	Population census, average health status, waiting times and numbers, outcome quality, unmet need, equity of access and outcome, life expectancy, insurance coverage, service utilization, expenditure on health, operational efficiency, facility capacity health human resource capacity
5.	Mechanisms	Incidence and burden of Illness, payment basis, control of access, delivery, practice variation, health insurance, institutions
6.	Dynamics	Population growth, illness encounters, organizational and institutional change, economic shocks, political change, individual choice

Adopting an approach cited by Attride-Stirling (2001) using the argumentation framework described by Toulmin (1958), the answers to the first two questions are posed as *claims* to be *warranted* by the model as it meets its design requirements. Thus answering the theoretic question claims that (i) *the model shows how healthcare works as a single system*, and answering the design question claims that (ii)*the SMoH model is a sound representation of a typical healthcare system.* A third claim reflects the intended application of the model in a multidisciplinary environment, that (iii) *the SMoH model is a useful planning instrument.*

After addressing these claims, the chapter concludes with Boundary Conditions that qualify and summarize the arguments advanced in this approach. The summary reveals the conditions under which the model represents healthcare, and the extent to which the system construct successfully generalizes healthcare.

8.3 Claim 1: Healthcare works as a single formal system

From a knowledge perspective this is the key finding of this research. Although the healthcare literature is replete with theories and propositions describing clinical, operational and economic structures and mechanisms, the systems model in its several versions shows that the *flows* of information, treatment and payment serve to connect these elements as a single functioning system.

The introduction to this dissertation mentioned as motivation the frequent scholarly advice that comparison of healthcare policies and performance should be based on a systems view. The review of the literature of healthcare models revealed frameworks that address structure, or categorisation, or guidance on policy formation, for example. This model represents healthcare as a system that is whole, causal and dynamic.

The warrants for this claim have their origins in the thematic version, SMOH-t, relying as it does on the analysis of the peer-reviewed work of healthcare domain experts. They are clarified as a formal specification in the ontology version, SMOH-o. Both versions identify entities and their properties and behaviours across all the relevant domains, synthesizing them first as low level collections and as higher level systems that connect to and influence each other by means of flows.

The dynamics of these systems arise from at least two categories of events. The first category includes events beyond the intention control within the healthcare system. The thematic version of the model, SMoH-t, identified demographic changes, technological advances and economic shocks as instances of such events. On the other hand, other events are deliberately designed as interventions with the intent of evoking change. Funding for example, or diagnosis and treatment are matters choice and decision. Policy change falls into this category.

From the perspective of the overall system, the significance of those types of events is in their influence and the responses they evoke *across the boundaries of the major systems*. The responses to treatment in the Life Course system are due to the conversion of resources in the Provision Network. They in turn are due to funding and payment processes in Payment Exchange, which ultimately are influenced by individual contributions either as payment or in taxes.

The systems at the top level are functionally, essentially and inexorably linked as a single system.

8.4 Claim 2: SMoH is a sound representation of a healthcare system

There are three aspects to this claim. The first relates to how, and how well, reasoning about SMoH allows users to draw conclusions about phenomena in a healthcare system – how well it meets the surrogative reasoning condition. The second aspect addresses how the model's design supports its purpose as a particular epistemic representation – in this case supporting explanation and prediction.

Model theory suggests that representation of a target by its model is first established when it satisfies the surrogative reasoning condition: i.e., *that there is a mapping from properties, relationships and functions in the model on the one hand to corresponding properties, relationships and functions in the target on the other*. Meeting that condition means that deductions reached in the model's artificial environment can be imputed with confidence in the target in the real world. That confidence, its *soundness*, relies both on the *validity* of the deductions internal to the model, and evidence in the real world of phenomena that bear out the *truth* of the inference. Evaluation of the model occurs from both perspectives. As a specified ontology, SMoH as a representation is *valid* in satisfying the fundamental requirements of an epistemic representation, and in displaying behaviours and explanations it aligns as evidence of its *truth* with some constructs and historical trends reported in the literature.

8.4.1 SMoH is *valid* to a degree.

The inferential validity of a model is a function of its components and structures – can claimed conclusions be deduced logically from those functional relationships? The design of this research is based on philosophical accounts and logical principles that add depth to understanding those components and structures – what they are and how they do what they are intended to do. The validity of SMoH, the systems model of healthcare, rests on its alignment with those accounts and principles. It contains a representation whose structures are keyed to a target system. As required by its epistemic purpose, the representation is specified as a system. And in meeting the requirements for interpretation and explanation, the representation is described in styles appropriate to the model's various intended users.

A systems model of healthcare is presented. As a model, it conforms to the requirements of an adequate representation as a scientific model: it satisfies the surrogative reasoning condition that outcomes of hypotheses examined in the context of the model may be imputed to the context of a real world target system. The theoretical foundations of the model are traced to constructs, propositions and variables observed in the real world by domain experts and reported in the academic literature. These foundational components are restated as system specifications, and then implemented in a form chosen for ease of interpretation. In this way, using three styles (i.e., versions) in which it progressively represents the target, the model meets to varying degrees the *epistemic goals of predicting, explaining and exploring how healthcare systems work*.

It is a representation in that there is a mapping from the object to the variables of interest in real world systems. But is it explanatory? Can it be used as an experimental instrument?

To the degree that choices among options may be imposed on the model (as scenarios, for instance) the model is capable of representing counterfactuals. Because the model may be configured with variations in properties, and each configuration assessed in a different scenario, counterfactuals may be readily examined, and in this sense it is explanatory.

8.4.2 SMoH is *true* to a degree.

From one perspective, the model presented here is a *valid* model of healthcare. As a specified ontology, it meets the fundamental requirements for epistemic representation and reveals counterfactual dependencies that support surrogative reasoning and interpretation. From the other perspective, the model satisfies its claim – to a limited degree – of *truth* in representing target healthcare systems in the real world. The second looks outwards, asking how well it meets its claim to represent its targets. Both evaluations, however, implicitly consider the degree to which the model can be generalized to the real world. These boundaries are set by the empirical inputs used as foundations of SMoH, and by the execution of the three methods in the methodology.

Recall that Bokulich (2011) speaks, not just of counterfactuals, but also of justificatory steps, of which she identifies two possible forms. The first presumes an existing, inclusive theoretical structure – a covering law – that has been accepted as valid and has been faithfully incorporated into the model. The second presumes that the model has been built from the bottom up using and linking established theories with narrower boundaries. It is a basic tenet of this dissertation, that such an integrated, top-down framing is not available. The analysis identifies choice as a relevant mechanism. The parsimonious treatment approaches the chooser as rational.

The truth of the model is a measure of alignment of phenomena in its artificial environment with evidence of corresponding phenomena observed in the real world. The truth of SMoH rests on its provenance of its representations in the qualitative content of experts' publications. On a separate basis that truth is also established through alignment of findings derived from experiments in the model with observations reported in the healthcare and systems literature but intentionally held back from the empirical data on which the representation is based. These experiments range from patterns that emerge as insights into complex phenomena, to thought experiments using simple scenarios and to a more complex simulation where SMoH-s is configured to parameters of the healthcare system in a specific country such as the Netherlands, for which evidence of its evolution has been well reported (Helderman *et al.*, 2005; van Ginneken, 2015).

Validation of models in general, and of simulation in particular, is discussed in detail in subsection 2.3.3. One test in particular applies in the context of this dissertation – the provenance of the data on which the model is based. The methodology emphasizes the quality of the empirical data used in specifying the model with the expectation that acceptance of the model would rest largely on this criterion. For models of this type, this appears to be the norm. For example, GMSIM, the Gruber Microsimulation model (Gruber, n.d.), on which was based the Affordable Care Act in the United States, was validated mainly in retrospect (Gruber, 2011).

Micro data

Most of these tests of truth are based on qualitative warrants, describing predicted and observed changes in state without numbers. Where quantitative comparisons are made, the model uses estimated micro data for all actor properties and elasticities. This is adequate to the purposes of the *what if* demonstration scenarios considered here, where only a low level of precision is required. Quantitative predictions such as those used by national statistics offices for specific policy design will require access to micro level databases. The model architecture is already designed to accept such empirical data.

8.4.3 Thought experiments

The following sections explore the model in both its thematic form and as a software simulation. The thematic exploration takes the form of *gedanken* thought experiments, while the simulation attempts to replicate some of the known evolution of healthcare policy decisions in the Netherlands.

Tested with thought experiments, the thematic version of the model explains some observed phenomena in terms of fundamental constructs. The ontology version exposes the dynamic of social mechanisms, but in the absence of quantitative data, has limited predictive capabilities. The simulation version is limited by the quality of data available or imputed in the configuration of scenarios.

The thought experiments proceed in three steps, beginning with a highly simplified configuration of a model constrained by many assumptions, and moving through successive steps in which some assumptions are relaxed. Each experiment predicts outcomes that are relevant to the functioning of a healthcare system.

Baseline experiment #1: Stable system

In this configuration, almost every variable is simplified and held constant.

- Assume:
  - Constant population: birth rates and death rates are equal.
  - A single type of illness, with fixed and predictable acuity and duration
  - A single diagnosis and a single treatment for that illness that shortens the duration of the illness.
  - Existing capacity (unspecified) of resources for providing treatment
  - Capacity may be added suddenly.
  - Universal coverage of health costs: every individual receives care when requested at no personal cost.
  - Retrospective payment to providers for all costs incurred in providing requested treatments.
  - Fixed price of treatment.
  - Total funding is determined by the total number of treatments and the price of treatment.
- Predicted outcomes:
  - If the existing capacity is at least sufficient to meet all requests as they occur, every person who encounters the illnesses receives treatment immediately and recovers as quickly as possible. Illness days establish an optimal baseline determined by the incidence rate and the size of the population.

Thought experiment #2: Coverage is optional or limited

- Assume
  - The constraint of universal coverage is relaxed and coverage is optional,
- Predicted outcomes:
  - only those individuals with coverage receive treatment.
  - All others recover at the slower rate of the untreated illness.
  - Illness days increase.
  - Costs are reduced in proportion to the number with coverage.
- Or assume
  - The scope of coverage instead is limited.
- Predicted outcome:
  - only those individuals who have resources to make up the difference in price will receive treatment.

Thought experiment #3: Population varies

- Assume
  - The population grows, everyone receives treatment until the existing capacity has been reached.
- Predicted outcomes:
  - Once that limit is reached, some requests are delayed.
  - When treatment is delayed, recovery time is less than optimal, and illness days increase.
  - When extra capacity is added the delays are corrected for those waiting, and no longer occur for new requests.

Increased incidence of the illness increases the number of requests with the same effect as a growth in population and with the same consequences. The two may be associated if incidence is associated with aging, and if the population age profile changes even with a static population census.

Thought experiment #4: Treatment varies

- Assume
  - Capacity availability is constrained by funding.
  - Funding is constrained and treatment is modified through process or efficiency improvement.
- Predicted outmode
  - Capacity increases and maintains treatments.

Thought experiment #5: Both diagnosis and treatment vary

- Assume
  - Requests continue to increase.
- Predicted outcome
  - The numbers delayed increase cumulatively.
  - The length of delay for each successive individual increases.
- If the restriction of a fixed diagnosis is relaxed, the diagnosis may take account of the adverse effect of a growing waiting list, and electively chose a treatment instead that requires fewer resources, relieving the pressure on capacity. Individuals receiving this reduced treatment will experience a slower recovery. Illness days will increase.

Conclusion

These sample sequence of thought experiments suggest that the behaviours of the model, under various simple conditions, generate behaviours that are recognizable in the real world of healthcare. The implementation in the more structured environment of the healthcare system in the Netherlands, reported earlier in subsection 7.5.2 adds strength to the suggestion. Those results are summarized here.

8.4.4 Assessment of results

The implementation of a representation of the healthcare system in the Netherlands was described earlier in subsection 7.5.2. The model's reported results in those simulated scenarios compare favourably with the outcomes observed in the healthcare system of the Netherlands over a three decade period in which interventions were introduced to manage growing social and economic challenges. In the spectrum of tests of validity previously referenced in Sargent (2005) the results of the comparison exercise meet the definition of an *operational validation* (*ibid*, p.133), further refined as a *historical validation* (*ibid*, p.134) if only at the very modest level of precision.

The configurations of the model establish the boundary conditions of this instance of the model for each of the scenarios. They constrain the estimates to only a coarse-grained level, which are significant largely in indicating the direction of changes over time.

8.4.5 Provenance as validation

Validation is discussed in detail in setting out the questions in the discussion of boundaries in chapter 2. Of the options identified by Sargent (2005) in that discussion, one test in particular applies in the context of this dissertation – the provenance of the data on which the model is based. The methodology places a strong emphasis on the quality of the empirical data used in specifying the model with the expectation that acceptance of the model would rest largely on this criterion.

8.4.6 Complex phenomena

Inspection of the model's structures and dependencies reveals that it generates some complex behaviours that are observed in the real world.

Path dependence

Path dependence arises in the model as a result of more fundamental linkages between system elements. It can be deduced in system terms as recurring choices by individuals or groups that do not change because changes in the larger context are not sufficient to exceed thresholds in the choice options. Institutional norms, for instance, or peer sentiment must change also if the system is to react to an intervention as an external stimulus. Recall that Granovetter (1978) explained changes in overall group behaviour in terms varying thresholds used by individuals in reacting to behaviours observed in one another. Similarly, Hall (1993) notes that the extent participation by actors varies with the level of change required. Changes in method (and hence targets) can be realized locally, whereas changes in process or strategic direction call for broader involvement across a system.

Conjuncture (where paths converge to produce enhanced reults (Evans, 2005; Wilsford, 1994)) can similarly be deduced from the mechanisms. Freshly different choices occur when accompanied by changes in the greater context or when the stimulus is sufficiently large. With substantial changes such as the formation of coalitions of Actors who can choose, or when an influential political actor emerges, *windows of opportunity* as described by Tuohy (1999a) open up.

Tipping points

There is no evidence that healthcare is in or close to dynamic equilibrium. That would be when the system adapts to external changes without compromising its goals of which there are three: stationary demand, flexible and adaptive supply to accommodate variation and adaptation.

Control: the locus of power

There is no single, constant locus of power in this model. Every actor participates in activities in one or two of the global themes; this is the highest level at which activities are generated and reactions occur. Through these activities, power is exerted by individuals acting alone or in groups or coalitions. There are no activities at the top level. There the three global themes constrain one another - each exerting exogenous influences on the context of the other two through the exchange of flows. In that way, the outcomes and outputs resulting from competing influences local to one theme become only contextual in the other global themes; the locus of power shifts with changes in the flows of those outputs. This is characteristic of distributed systems that emerges s a property of models based on microfoundations.

This model meets the triple requirement that it be comprehensive, dynamic and causal. It maps a wide and deep landscape of healthcare knowledge to concise structures of elements and themes that are logically assembled as groups and layers within a single *comprehensive* representation. It reveals that healthcare is composed of three systems associated with the major actors in healthcare and that these form a system by virtue of the connecting flows between them. The findings reveal the *dynamic* nature of the model in the mechanisms that explain how the properties and states of elements change and how as a result the outcomes not only change, but do so concurrently. Finally, and crucially, the model's specification also includes the *causal* mechanisms that arise endogenously as a result of the structural connections among the elements of the system, and those that occur exogenously, both as shocks and as deliberate interventions.

8.5 Claim 3: SMoH is a useful planning instrument

The thought experiments here approach the model's validity from a hermeneutic perspective (Feinstein and Cannon, 2003), exposing behaviours that appear to *make sense* in light of common observations of healthcare.

The methodology of this dissertation, and the versions of the model that it produces, address this criterion of acceptability to varying degrees. The themes version – SMoH-t – is built on theoretical foundations from the literature that together satisfy Bokulich's requirement of a justificatory step (Bokulich, 2011), but it is expressed in a narrative and graphical style that is difficult to configure as scenarios, or to manipulate experimentally. Translated and expressed in SysML, the structured systems language, the ontology version – SMoH-o – more readily captures and expresses the structural, dynamic and causal and dependencies of healthcare systems, including the underlying invariants and the variations that distinguish different instances in the real and observed world. As an ontology, this model can be extensive, both in its breadth and in its hierarchical depth, but it is still difficult to interpret and apply outside a technical context. The third simulation version – SMoH-s – suggests how the technically complete but cognitively opaque ontology model can be implemented as a user-friendly, interactive simulation that supports interpretation and learning by users skilled in other professional disciplines.

8.5.1 Borrows and extends existing models

The model reflects characteristics of exiting models of healthcare. The agent based approach, exposing the heterogeneity of the properties and methods of the Person agent has much in common with the treatment of individuals in the microsimulation models reviewed previously (subsection 3.1.7). The similarity between the approaches is most evident in the dynamic microsimulation models such as POHEM (Hennessy *et al.*, 2015; Will *et al.*, 2001; Wolfson, 1994)and LifePaths (Spielauer, 2013), where the trajectories over time of variables of interest are generated functionally for every individual. The agent based approach retains this capability, but extends it by adding connections among individuals – and indeed among other types of agents – that can influence the generating functions externally as well.

Simulating the flows of information, treatment and payment is similar to system dynamic models that examine the allocation of resources and services across diverse sectors of a healthcare system (Esensoy and Carter, 2017; Esensoy, 2016), or that assess requirements for care of older members of the population (Ansah *et al.*, 2014, 2013). System dynamic models in general operate at an aggregate level, working with accumulated values for populations. Flows are calculated using algebraic integral and difference[1] functions that apply smoothing algorithms to reduce artifacts. SMoH-o represents the same flows and stocks, but at a more granular level. This exposes sensitivity to the heterogeneity among individual Persons (and Providers). It also allows accumulation of flows on an event-by-event basis, avoiding the need to apply mathematical formalisms, and the distortions that smoothing may introduce to the observed outcome variables.

8.6 Boundaries of SMoH as a systems model of healthcare

The systems model SMoH is designed and constructed as a limited and parsimonious representation of healthcare. As a consequence, the evaluations also specify boundaries out of necessity so that users may understand that inferences beyond these boundaries cannot be relied upon as sound. Limitations that set these boundaries emerge in the range of the empirical data – the data set – in the application of the three methods, thematic analysis, systems language translation and software implementation – and in the use of data that are approximate but largely synthetic.

8.6.1 Boundary conditions

The model specification builds on the goals, indicators, assumptions and constraints. This model can represent a real healthcare system to a limited extent only. It is bounded in numerous ways. The themes depend on the selection of articles in the corpus of data, and indeed on the scope and criteria of the literature search. They depend also on the interpretation and encoding of quotations. Analogously, the translation from narrative to the language of system specification depends on the fluency of the analyst in both vernaculars. The quality of any model as a representation is bounded by the elements ultimately selected for inclusion in a simulation. And finally, the precision and accuracy of reported outcomes depends on the availability and quality of empirical data.

The model presented here approaches these limitations constructively. In the first instance the format of the specification includes declaration of the origins and scope of parameters as boundary conditions. Likewise the configuration of a given simulation incorporates choices of boundaries.

[1]An necessary adjustment that treats as discrete the underlying continuous differential equations that are the theoretical foundations on which system dynamics is based.

8.6.2 SMoH-t boundaries

In the first stage of thematic analysis, the model portrays, at the global level, three themes that are linked by three types of flow, where each theme combines levels of inner themes that describe the activities and relationships of individual actors - people, physicians, hospitals, government, insurance firms and others. The content of this themes model is rich in detail and highly granular. It is limited mainly by the extent and rigour of the initial coding processes; with a sufficient volume of quotations, a saturation effect indicates that the collection of codes is representative of the concepts in the selected documents, strengthened by the breadth in perspective of the documents in the data sets.

The themes version of the systems model as reported here is bounded in two dimensions. The representation is bounded on the one hand by the extent and variety of the texts chosen as a data set; the codes and associated concepts included in the model are limited to those found in that set. Logically, this excludes new contributions to the literature. The reproducible nature of the methodology allows updating of the model where necessary, and revision of this boundary.

The second limitation of the themes model lies in its use of narrative and network graphics. These styles support tracing the models elements and behaviours back to the supporting research in the literature, but they are cumbersome as vehicles for exploring and explaining how healthcare works as a system in its three major dimensions.

The other two versions of the model address this limitation.

8.6.3 SMoH-o boundaries

The SysML specification is a repository in which the details of the underlying model are retained. However, while the extent of the specification is important for retrieval during ongoing research, the specification reported here is limited to its use as an intermediate step in preparing a small scale software implementation that can demonstrate the comprehensive, dynamic and causal character of the systems model.

The ontologic model adds structure and precision to the concepts abstracted and distilled by the themes model as entities and behaviours in systems of systems. SMoH-o resolves ambiguities of entities and properties, adding formalisms of hierarchy and algorithms to the relationships. This version still inherits the limitations imposed on the themes version by the extent of the data set of published texts, but it establishes a framework that more readily supports analysis and exploration.

As a framework and repository of specifications and diagrams, this version is limited as an exploratory tool. SysML is a language for experts in systems engineering; it is not friendly to experts in other domains. And as with most ontologies, the resulting repository is difficult to explore and probe using the same constructs with which it is built. This limitation is exacerbated by the essential dynamic and causal nature of the underlying representation of healthcare. Instruments are required to allows users to examine and form explanations of the phenomena observed or intended.

8.6.4 SMoH-s boundaries

In this research, a software based simulation SMoH-s is used the overcome the dense and arcane limitations of the ontology version of the model. As representation of a target healthcare system it islimited; within the scope of the research question posed, the simulation version is presented primarily as evidence of feasibility. SMoH-s implements a limited set of constructs, sufficient to meet minimally the wholeness requirement that indicators for people, providers and payment be reported.

One last constraint, which may be termed a "provisional boundary", is linked to the data employed in SMoH-s. In constructing the simulation model, default values are assigned to all parameters and variables in the simulation models. These values are synthetic – they have no empirical value, and are based only on coarse approximations to real values reported in the literature. The software architecture of the model is designed to accept empirical data, but this facility has not been enabled in the implemented model reported here. Running the model without updating of these values provides a baseline reference scenario against which another other configured may be run. Scenarios with more robust empirical data are beyond the scope of this stage of the research.

This version of the model uses estimated micro data for all actor properties and elasticities. This is adequate to the purposes of the *what if* demonstration scenarios considered here, where only a low level of precision is required. Quantitative predictions such as those used by national statistics offices for specific policy design will require access to micro level databases. However, this is not a permanent constraint as the model architecture is already designed to accept such empirical data.

8.7 Open systems and contingent thinking

The assessments in this chapter so far identify boundaries that arise from the methodology: the processes of abstraction and of simplification place limits on the extent to which SMoH may be generalized when applied in practice. This section addresses boundaries of a different kind - those that delineate the extent of any particular system, separating its member entities from that system's environment. The delineation is fundamental in specifying systems of all types, but is of particular relevance in social systems such as organizations, institutions and even communities and populations.

In considering boundaries in healthcare systems, there are two topics of particular interest: the distinctions between open and closed systems, and the place of contingency theory. Both topics have in common that they relate largely to *organizations* as systems i.e., to systems of people, and therefore of entities whose behaviours are subject to variation that is more than merely mechanistic.

8.7.1 Closed and open systems

The open/closed debate arises early in section 3.3 that elaborates system theory, as researchers look at how managers approach their challenges in shaping their organizations.

The closed system approach focuses attention on the inner workings of a given system as the entities within interact with one another - the exchanges of information and of resources producing results consistent with intended outcome of the organization and its managers (Thompson, 2003). The perspective originated in the early work on scientific management and in the application of deterministic parameters to functions expressed as mathematical formulations. The more recent attention to emergent behaviours in the context of chaos and complexity renews attention to closed system constructs.

The open system view addresses the organization in its broader context. This implicitly takes the view that a boundary defines a given system by separating the entities within - the endogeneities - from those in the environment outside the boundary - the exogeneities. The construct is mentioned by several researchers (Ackoff, 1971; Boulding, 1956; von Bertalanffy, 1950, 1972) extending attention to the influences of context and environment on the behaviours of systems. To some extent, the open/closed perspectives compete in that the former tends to focus on optimizing performance, while the latter attends to survival in the face of indeterminate change.

8.7.2 Contingency theory

Contingency theory is relevant in selecting policies and strategies with a view to maintaining or improving performance in the face of changes in the environment. The theory arises in the domain of open systems, when agents must choose actions and interventions in fulfilling their roles as stakeholders in the future of an organization. Externalities are not necessarily controlled, and they may even be unpredictable. Hence planners' attention is focused on approaches that might accommodate or at least anticipate such changes that could have an impact on the organization. Contingency theory examines conditions for the successful outcome of a given intervention, asserting that the diversity of conditions within systems and in its external context precludes a clearly superior solution. While earlier approaches to management are based on deterministic mechanisms, a contingent approach accepts that externalities are rarely completely defined or even knowable.

8.7.3 SMoH is an experimental instrument.

In representing healthcare as a system, SMoH exemplifies these theoretical constructs without loss of generalizability. The ontological version of the model, using the SysML specification constructs, explicitly identifies the boundaries within which a given set of elements exist, and shows the relationships among them that explain their behaviours. Since the specification allows that any entity may be treated as a system in its own right, the same construct exposes a given system as open to its containing environment. In its layered specification of smaller systems nested within larger ones, it allows attending to the inner mechanisms that characterize a closed systems approach by holding constant, or at least controlling for, changes associated with other peer or parent systems. The designation of individual systems as open or closed is at the discretion of the user of the model. Depending on the epistemological purpose for which the model is intended, the treatment of inputs may be either manipulated or held constant, in effect exploring with scenarios the degree to which the systems of interest are open or closed, respectively.

It is in the *application* of SMoH as a planning and experimental instrument that the designation as open or closed, if necessary, is relevant. By identifying and distinguishing exogeneities available for manipulation from those that may be beyond control, planners may explore and compare the outcomes of different strategies. This allows evaluation of each strategy in terms of the fit between structure and context. Although bounded by the scope and quality of data available in constructing the model, this meets one of original aims in developing a model that would be of practical use to people seeking practical solutions to healthcare's systemic challenges.

8.8 Chapter summary

This chapter examines how well the research questions are answered in the reported findings of the previous three chapters. The three versions of the model are reviewed, revealing how each provides a perspective that exposes the representation of healthcare as a system of systems. The claims are assessed as answers to the research questions, addressing in turn healthcare's systemic constructs, the model's soundness in representing those constructs and its utility as a planning instrument. The limits of the model's application are presented as boundary conditions. Application of the model has been discussed in the context of the open/closed systems debate and contingency theory.

Chapter 9

Conclusion: contributions and future directions

This dissertation has described the development of a model of healthcare as a system, prompted by the author's experience in the field over some decades, motivated by a curiosity about how the system works and fuelled by an engineer's interest in simulation as a vehicle for learning. The research at this stage is foundational and contributes to knowledge and to practice. However, its main contribution is as a foundation on which to build future investigations and designs. This concluding chapter echoes the issues of the introduction, summarizing the research as a whole, its unique and novel contributions to knowledge and practice, and the directions in which future work in healthcare could proceed to address the limitations of this existing work.

The title of this dissertation deliberately describes the work as progress in representing healthcare more fully as a system. The model presented here, in its three versions, makes it easier to see and to understand how healthcare works. It adds to knowledge mainly by showing that the systems and the constructs known separately are in reality interconnected, an insight that offers a more complete understanding of how changes propagate both intentionally and not. It also exposes several factors that produce change, adding causality as a focus of the model.

The model represents healthcare as a system in a manner suited to effective exploration of policy interventions to meet the challenges of maintaining affordable and effective provision of care. The implemented software simulation has functional features that surpass other models in use at present for policy development. The research contributes to theory, methodology and practice in public health, healthcare economics and healthcare policy, and presents opportunities for refinement and extension using its reproducible methods.

9.1 Summary of the dissertation

This dissertation describes a new model of healthcare. It is sufficiently broad to expose important aspects of performance. It exposes behavior over time, and it incorporates mechanisms that explore alternative futures: it answers the questions that planners must ask.

The three perspectives version of the model provide complementary descriptions that together support a claim that insights gained from the model may with reasonable confidence be inferred in the real world. In thematic form it establishes credible links between the model's synthetic and stylized constructs and the concepts and observations with the real world of healthcare as described. As a system specification the model maintains a consistent repository of system details – the structures and behaviors of healthcare at its various levels of granularity. And as a simulation it behaves as an instrument that exposes a representation accessible to professionals of diverse backgrounds, enabling sharing of insights and of assessments and the pursuit of more ambitious and more promising solutions and reforms.

9.2 Contributions of this dissertation

The dissertation's contributions to knowledge are framed in a template suggested by Whetten (1989) with which the merits of a publication may be assessed. It is based on the *what*, *how*, *why* triad cited more than once in this dissertation. His criteria for the value of contributions to theory are listed as questions and addressed below.

1. *What's new?* The dissertation offers novel contributions. It proposes a new theoretic construct of healthcare as a whole, unified and constrained system; it contributes a user accessible experimental model incorporating that construct for use in planning healthcare interventions. Its multidisciplinary methodology builds on theoretic foundation in related sciences, and is a replicable approach that enables correction and refinement of the model.

2. *So what?* The model is a unifying framework within which new strategies and plans can be assessed and evaluated, using existing concepts, insights and explanations that are as complete as possible and shared as widely as possible. The dynamic and causal design of the model supports experimentation to evaluate strategies a priori. The ingredients of a plan should include not only the steps to take to succeed, but those to take if things don't turn out as expected. Formation of coalitions is enabled when potential outcomes can result from a common framework. And finally, the reproducible methodology design aligns with a growing research trend in open and shared data.

3. Why so? This model is built on established research foundations. It applies recent advances in model theory and uses an established language

in which to specify the entities, properties and behaviours of healthcare. The connections between the model and the real world are unambiguously identified, explicitly supporting the surrogative reasoning condition essential to using models to explain the real model.

4. Why now? This work is opportune for two reasons. In general it offers new approaches at a time when the challenges in maintaining services are trending in the wrong direction and show little prospect of reversal. At the time of writing this dissertation, options for refinement and even redesign of major portions of the healthcare system have been debated vigorously in Canada, the United Kingdom, the United States and Ireland (to name a few). The issues are current, and the availability of extended theory and a new instrument is timely. The dissertation's methodology also avails of emerging technical and technological advance reducing barriers that previously hindered implementation of progressive ideas. These include improved computing capacity, and an expanding adoption of agent-based modelling as a simulation method.

5. Who cares?: In so for as this model enables productive consideration of possible solutions, this model would be of interest and value to a variety of people and organizations whose goal is the provision of healthcare to those who need it. However, this optimistic assessment of the work is warranted only weakly. Despite widespread research in and design of models to support problem solving and reform in healthcare, there is little evidence of uptake of these models by policy making practitioners. In the literature, reports of models provide descriptions of the approach and of the findings, but seldom reference ongoing adoption of policies resulting from applying the models. The attention in this model to the incorporation of suitable interpretive styles may reduce that reluctance to adopt either in research or in practice.

But this SMoH model, and indeed any model, is limited. It is in addressing these limitations that the the last version of the model, SMoH-s, offers new insights. In the simulation, boundary conditions are viewed not simply as caveats on the application of a model, they are elevated to the level of essential elements in the specification of a model, isolating and exemplifying the features of a model that are chosen for epistemic purposes to represent the target or outcome in question.

9.3 Future work

Future work will refine the model in its several version, and in the simulation version, SMoH-s, will add data sources and extend the model's boundaries to include new areas of enquiry and of design. There is plenty to explore in moving the boundaries outwards. The detail of the existing model can be strengthened as necessary by applying the methods more rigorously, and by inviting other researchers to join in coding, translating and implementing simulations. The more enticing opportunities lie in using the simulation model (built as it is on solid thematic and systems modeling foundations) to explore new domains, both in healthcare and beyond, such as complex adaptivity, behavioural economics and embedding neural networks.

9.3.1 Refine models

The systems model, SMoH, in its three versions is ripe for refinement and extension. The simulation version uses only a fraction of the specification assembled in the repository, and the thematic model can also be extended to include a more detailed set of mechanisms, both for incorporation in the model as evidence of its inferential capabilities.

9.3.2 Choice and power

The current version of the systems model does not include the social mechanisms of personal and individual choice. The implementation of policy change particularly at Hall's level 3 (as discussed in subsection 5.6.2), substantial changes to a major strategy require the collaboration or, at a minimum the acquiescence, of other stakeholders. The eventual implementation of a policy change results from prior changes in power and influence that accumulate as pressures first, before eventually reaching (or not) a point of inflection when the change is executed. Within the model, this will require further elaboration of the concepts of influence and pressures as factors in specifying decision making mechanisms.

9.3.3 Micro data

The model is bounded by the precision of the input data, and by the validity of the relationships as expressed in functional form. The growth of open data policies at the level of national governments may offer access to more usable data. The addition of artificial intelligence in the form of learning networks may also offer more robust expressions of the relationships.

9.3.4 Adaptivity

Several scholars in various disciplines ascribe complexity to healthcare, associating certain characteristics of complex adaptive systems with observed patterns in healthcare. The discussions are typically of a narrative nature, often allegorical or metaphorical, but rarely structural. Future exposure and elaboration of relationships among the systems are various levels will provide opportunities to apply methods of nonlinear analysis to the systems established here, and possibly discover conditions that could lead to tipping points to new dynamically stable system states.

9.4 Living life in reverse

On a personal note, the pursuit of this research at the end of an active career in healthcare administration has felt like living life in reverse – returning to concepts that now fascinate, but that this author wished he had appreciated better, many decades ago when they were originally introduced – and yet finding other concepts that are brand new (to him) that would have been very useful during the course of his work, had he only been aware of them back then.

Beginning the work of this dissertation provided an opportunity on retirement to indulge an interest in the intersection of healthcare and systems thinking that had been set aside from many years. The learning has extended far beyond the original questions posed. It has shown the value of asking questions of others, and of asking new questions when the ones at hand are not enough.

That has been the story of this project. Asking how healthcare works was interesting in itself, and finding the abundance of answers in the literature was gratifying. The project might have ended there, but for the nagging difficulty in describing and applying that borrowed knowledge. And so it grew, first in the domain of systems engineering, and then into the realm of software development.

Wise mentors advised against approaching the DBA as the "rest of your life". This author is content that, in retirement, the continuing project can in fact become a part of that life.

Appendices

Appendix A

Data sets

ATLAS.ti Report

Healthcare systems 2.0.4

Documents grouped by Document Groups

Report created by Neil McEvoy on Aug 10, 2017

Comparative

3 Documents:

- **25 Siciliani: Tackling excessive waiting times**
- **37 Health Systems Institutional C.pdf**
- **42 Commonwealth Fund: Why Not the Best? Results fro.pdf**

Determinants

5 Documents:

- **18 Grossman: The human capital model**
- **19 Or: International differences in t.pdf**
- **20 Wranik: Healthcare policy tools as determinants of efficiency**
- **21 Andersen: Revisiting the behavioral model**
- **46 Boyd: Disease, illness, sickness, he.pdf**

Frameworks

4 Documents:

- **22 Donabedian: The quality of care - How can.pdf**
- **38 Aday: A framework for the study of a.pdf**
- **40 Donabedian: Quality, cost, and health an.pdf**

44 Smith: The economics of health system.pdf

HiT reports

17 Documents:

- 1 HiT Template
- 2 Switzerland HiT report
- 3 Germany - HiT Report
- 4 Italy - HiT Report
- 5 Austria - HIT Report
- 6 Norway - HiT Report
- 7 Canada - HiT Report
- 8 Denmark - HiT Report
- 9 Sweden - HiT Report
- 10 United Kingdom - HiT Report
- 11 Portugal - HiT Report
- 12 Belgium - HiT Report
- 13 France - HiT Report
- 14 Netherlands - HiT Report
- 15 Spain - HiT Report
- 16 Ireland - HiT Report
- 17 Finland - HiT Report

Mechanisms

12 Documents:

- 18 Grossman: The human capital model
- 21 Andersen: Revisiting the behavioral model
- 23 Granovetter: Economic Action and Social Structure
- 24 Evans: Fellow travelers on a contested path
- 25 Siciliani: Tackling excessive waiting times
- 26 Quinn: The 8 Basic Payment Methods in Halth Care
- 28 Okma: Managed competition for Medicare
- 29 Okma: Swiss and Dutch "consumer-driven health care"
- 41 Paris:Health Systems Institutional C.pdf
- 43 Hall: Policy paradigms, social learning
- 47 Arrow: Uncertainty and the welfare ec.pdf
- 48 Geoffard: Incentive and selection effect.pdf

Policy and Governance

5 Documents:

- 30 Rochaix: State autonomy, policy paralysis
- 32 Tuohy: Dynamics of a changing health sphere
- 34 Tuohy: Canada Health Care Reform
- 35 Helderman: The rise of the regulatory state
- 36 Smith: Leadership and governance in seven health systems

Reforms

5 Documents:

- 27 Okma: The Netherlands From Polder Model
- 31 Saltman: Renovating the commons Swedish Health Reform
- 33 Oliver: European health systems reform
- 34 Tuohy: Canada Health Care Reform
- 45 Bevan: Choice of providers and mutual.pdf

No document group

1 Documents:

- 39 About WHO : Definition of Health.pdf

Appendix B

Codebook

- Core actors
- Core flows and abstractions
- Basic themes associated with persons
- Basic themes associated with provision
- Basic themes associated with payment
- Organizing themes
- Global themes

Actors - core

Codes

Report created by Neil McEvoy on Jan 22, 2018

● Government

Used In Documents:
🗎 2 Switzerland HiT report 🗎 3 Germany - HiT Report 🗎 6 Norway - HiT Report 🗎 8 Denmark - HiT Report 🗎 9 Sweden - HiT Report 🗎 13 France - HiT Report 🗎 15 Spain - HiT Report 🗎 16 Ireland - HiT Report 🗎 24 Evans: Fellow travelers on a contested path 🗎 29 Okma: Swiss and Dutch "consumer-driven health care" 🗎 32 Tuohy: Dynamics of a changing health sphere 🗎 36 Smith: Leadership and governance in seven health systems 🗎 37 Paris: Health Systems Institutional C.pdf 🗎 41 Paris:Health Systems Institutional C.pdf 🗎 45 Bevan: Choice of providers and mutual.pdf

Quotations:
💬 2:7 Today, as the result of a slow but steady process of greater centralization over recent decades, the…
💬 3:9 Sickness funds pay for health care providers, with hospitals and physicians in ambulatory care (just…
💬 6:29 The Ministry of Health distributes its budget among the RHAs, municipalities, counties and the HELFO…
💬 8:1 The health system can be characterized as fairly decentralized, with responsibility for primary and…
💬 9:9 Public hospitals are grouped
💬 13:1 The French health care system is of a mixed type, structurally based on a Bismarckian approach with…
💬 13:3 Jurisdiction in terms of health policy and regulation of the health care system is divided among the…
💬 15:1 The majority of regional governments have been presided over by either the PP or the PSOE and that s…
💬 15:2 The completion of the devolution process in 2002 was followed by the passing of the SNS Cohesion and…
💬 16:1 These reforms aim to make the system more primary care driven. The reforms, in part, were made possi…
💬 16:24 If expenditure as a proportion of gross national product (GNP), rather than GDP is used1 then Irelan…
💬 24:3 In the first phase, all these countries put in place more or less universal and comprehensive system…
💬 24:5 In the three Scandinavian countries, public provision of or support for health care had “always” bee…
💬 24:7 Who gets care, who pays, who gets paid
💬 29:3 government will (largely) step back, letting the market forces allocate scarce resources efficiently…
💬 32:1 The first relates to the balance of influence across key com- ponents of the politicoeconomic struct…
💬 32:4 Different balances of influence imply the pre- dominance of different lines of accountability. State…
💬 32:5 In very broad terms, state actors function within systems in which those in command ultimately are d…
💬 32:12 To understand the different histories of each national system in the 1990s, we must begin with the l…
💬 32:13 Canadian Medicare bears the marks of its birth in the 1960s, an era of economic growth, high public…
💬 36:1 Priority setting can be defined as a more or less systematic approach to distributing the

availabl…
💬 37:16 Analysing health expenditures by financing agent is another useful way to characterise financing arr…
💬 41:36 Degree of decentralisation of decision-making 195. Decentralisation has been employed in public and…
💬 41:37 Resource allocation between regions and sectors of care does not always result from a decision- maki…
💬 45:4 In the early 1990s, the Dutch government had effective systems for controlling prices, the number of…

Linked Codes:
— role → ● Payer

Groups:
Actors Actors - core

Comment:
> Government is a unque actor associated with a healthcare system, having legal authority of the state to enforce regulations exercised by elected representatives who rely for their authority the renewing mandate of the population.

● Payer

Used In Documents:
📄 6 Norway - HiT Report 📄 9 Sweden - HiT Report 📄 13 France - HiT Report 📄 24 Evans: Fellow travelers on a contested path 📄 41 Paris:Health Systems Institutional C.pdf 📄 45 Bevan: Choice of providers and mutual.pdf

Quotations:
💬 6:29 The Ministry of Health distributes its budget among the RHAs, municipalities, counties and the HELFO…
💬 9:22 The mechanisms for paying providers vary among the county councils, but payments based on global bud…
💬 9:23 primary care providers is generally based on capitation for registered patients, complemented with f…
💬 13:17 However, SHI only funds around three quarters of health spending, leaving considerable scope for com…
💬 13:18 VHI provides reimbursement for co-payments and better coverage for medical goods and services that a…
💬 13:19 Funding for long-term care for the elderly and disabled is partly ensured by a dedicated fund create…
💬 13:20 Since 2004, hospital acute care is paid by using a type of DRG payment method (tarification à l’act…
💬 13:21 The main objectives of the reforms to the health care system of the last decade were to contain SHI…
💬 24:3 In the first phase, all these countries put in place more or less universal and comprehensive system…
💬 24:12 In the second, they all find themselves confronting the relentless pressures for cost escalation inh…
💬 24:13 The German financing system has preserved a very large number of sickness funds, but the German gove…
💬 41:32 Prices paid by third-party payers are most often set or negotiated at the central level (Table 26)….
💬 45:1 In the original model of the ‘internal market’ (1991–1997), DHAs became purchasers and hospitals ind…

Linked Codes:
← role — ● Government
← role — ● Person

Groups:

Actors Actors - core

Comment:

Payer is a generalization of actors whose primary behaviour is to flow Payment to Providers. Under various administgrative and regulatory arrangements in a given healthcare system, the Payer may include individual Persons who take a payment rule, or the state as funder of services under various schemes. The system amy also include specialist payer organizations, either as commercial firms or as corporatist entities associated with employers or professions.

Payment by payers is constrained to services and conditions agreed or imposed from time to time.

Person

Used In Documents:

2 Switzerland HiT report 6 Norway - HiT Report 8 Denmark - HiT Report 10 United Kingdom - HiT Report 12 Belgium - HiT Report 14 Netherlands - HiT Report 16 Ireland - HiT Report 18 Grossman: The human capital model 21 Andersen: Revisiting the behavioral model 24 Evans: Fellow travelers on a contested path 28 Okma: Managed competition for Medicare 29 Okma: Swiss and Dutch "consumer-driven health care" 37 Paris: Health Systems Institutional C.pdf 39 About WHO : Definition of Health.pdf 41 Paris:Health Systems Institutional C.pdf

Quotations:

2:2 Like many western European countries, Switzerland faces an ageing population, with the ratio of olde…
6:33 given the increasing proportion of older people in the population, the increasing use of new technol…
8:20 While life expectancy for a newborn boy increased by 20 years over the last century, it rose by four…
8:21 Regarding human resources, the number of physicians is experiencing a slight increase but recruitmen…
8:22 Self-rated health was also found to be correlated with educational level and employment status.
8:24 Since 1973, residents over the age of 15 have been able to choose between two coverage options in th…
10:11 In England, the total number of doctors working in the NHS was 140 897 in 2009 (132 683 WTE), which…
10:12 Reflecting on differences in health outcomes in England measured in terms of life expectancy and dis…
10:13 These adverse incidents contributed to death in 8% of cases. 4 Currently an increase in the number o…
12:10 Before July 2007, in order to qualify for preferential reimbursement, a patient had to belong to a s…
14:2 The reform introduced managed competition supervised by independent bodies. The health insurers, the…
14:19 The majority of the residents in nursing homes and residential homes are older than 80 years. Fig. 6…
14:20 Fig. 5.4 and Fig. 5.5 show that the number of physicians and nurses per 1000 population has grown ra…
16:22 Human resources are a key issue for the future of the health care service. The Government is committ…
18:1 Consumers are assumed to select that combination that maximizes their utility function subject to an…
18:7 First, an increase in the stock of health lowers the prob- ability of illness but has no impact on e…
21:1 Predisposing characteristics include age and gender
21:2 Health beliefs are attitudes, values and knowledge
21:3 Bothcommunityandpersonalenablingmyownempiricawlorkhavebeenidentified resourcesmustbe presentfor use…
24:7 Who gets care, who pays, who gets paid

💬 28:3 Third, the expansion of con- sumer choice has not worked as envisioned. In 2006, about 18% of Dutch…
💬 29:1 First, cost-conscientious and well-informed consumers who are mandated to take out health insurance…
💬 37:6 Naturally, consumer choice of insurer is a pre-condition for real competition in health insurance ma…
💬 39:1 Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.
💬 41:7 Consumer choice and competition between health insurers offering basic primary health care coverage…

Linked Codes:
— role → ● Payer

Groups:
Actors Actors - core

Comment:
> Person is a fundamental entity in a healthcare system. Each Person is an actor with properties and behaviours. From a systems perspective, a Person is specified as a "black box", i.e., the outward characteristics are notionally observable, but inner elements are opaque.

● Provider

Used In Documents:
📄 2 Switzerland HiT report 📄 8 Denmark - HiT Report 📄 9 Sweden - HiT Report 📄 10 United Kingdom - HiT Report 📄 12 Belgium - HiT Report 📄 13 France - HiT Report 📄 14 Netherlands - HiT Report 📄 16 Ireland - HiT Report 📄 24 Evans: Fellow travelers on a contested path 📄 32 Tuohy: Dynamics of a changing health sphere 📄 41 Paris:Health Systems Institutional C.pdf 📄 45 Bevan: Choice of providers and mutual.pdf

Quotations:
💬 2:17 The number of physicians and nurses has increased relatively strongly over the past two decades, whi…
💬 2:19 Ambulatory care is provided mostly by self-employed physicians working in independent single practic…
💬 8:2 The five regions are, among other things, responsible for hospitals as well as for self-employed hea…
💬 8:10 Many actors are involved in rehabilitation care within the health care sector, the social sector, th…
💬 8:23 The financing structure reflects attempts to control costs through global budgeting and upper limits…
💬 8:25 The quality of care for chronic conditions can be examined by looking at avoidable hospital admissio…
💬 9:21 Seven overall themes or areas have guided new initiatives since 2000: • continued specialization and…
💬 10:1 The GP is seen as the focal point for all primary care services in England; however, primary care is…
💬 10:14 Different examples of patient pathways are discussed in the sections that follow, particularly those…
💬 12:11 Partly as a result of the lack of referral structure between different types of hospitals in Belgium…
💬 12:12 However, the total number of hospital beds did not decrease as desired by the government, which led…
💬 12:13 Health care is provided by public health services, independent ambulatory care professionals, indepe…
💬 13:9 Workforce forecasting and careful planning of educational capacity is mostly made at the national le…
💬 14:2 The reform introduced managed competition supervised by independent bodies. The health insurers, the…

💬 14:10 The 1987 Dekker Plan, called “Willingness to change” (Bereidheid tot Verandering) was another attemp…
💬 14:12 Primary care has a wide variety of providers, such as GPs, physiotherapists, pharmacists, psychologi…
💬 14:14 Private insurers and sickness funds merged into large companies in order to strengthen their competi…
💬 14:15 Another argument was obtaining sufficient countervailing power against health insurers.
💬 16:23 The Irish health care system remains predominantly tax funded. In 2006, 78.3% of total health expend…
💬 24:7 Who gets care, who pays, who gets paid
💬 32:1 The first relates to the balance of influence across key com- ponents of the politicoeconomic struct…
💬 41:15 Organisation of health care supply 79. The organisation of health care supply potentially influences…
💬 41:31 This part of the questionnaire sought to assess the level of autonomy of hospital managers hold in t…
💬 41:35 Co-ordination of care 190. Questions 63 to 67 collected information on different aspect of care co-o…
💬 45:1 In the original model of the ‘internal market’ (1991–1997), DHAs became purchasers and hospitals ind…
💬 45:3 An emphasis on patient choice for elective care. > A new reimbursement system, ‘Payment by Results’…

Groups:
Actors Actors - core

Comment:
> Provider generalizes role of individual actors who have the capabiity of producing and the capacity o deliver treatments to individual Persons. Providers (either as individuals or as organizations) process Information and Payment in fulfilling their resp[ective roles. There are several types of Provider, distinguished by their properties (resources and assets) and behaviours (skills and processes).

Flows and abstractions - core

Codes

Report created by Neil McEvoy on Jan 22, 2018

• Illness

Used In Documents:
🗎 3 Germany - HiT Report 🗎 8 Denmark - HiT Report 🗎 10 United Kingdom - HiT Report 🗎 14 Netherlands - HiT Report 🗎 18 Grossman: The human capital model 🗎 19 Or: International differences in t.pdf 🗎 21 Andersen: Revisiting the behavioral model 🗎 22 Donabedian: The quality of care - How can.pdf 🗎 24 Evans: Fellow travelers on a contested path 🗎 30 Rochaix: State autonomy, policy paralysis 🗎 31 Saltman: Renovating the commons Swedish Health Reform 🗎 38 Aday: A framework for the study of a.pdf 🗎 39 About WHO : Definition of Health.pdf 🗎 40 Donabedian: Quality, cost, and health an.pdf 🗎 46 Boyd: Disease, illness, sickness, he.pdf 🗎 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
💬 3:31 These results are supported by a growing technological infrastructure and the use of highly speciali…
💬 3:32 Nevertheless, diseases of the circulatory system still cause approximately 36% of all deaths in Germ…
💬 3:33 The mortality gradient in adult age groups is attributable primarily to cardiovascular diseases (208…
💬 3:34 Since 1993 the number of hospital discharges has been increased considerably for most of the conside…
💬 8:13 Other initiatives include the introduction of national clinical pathways for cancer and heart diseas…
💬 10:12 Reflecting on differences in health outcomes in England measured in terms of life expectancy and dis…
💬 14:21 In the same year, most deaths were caused by malignant neoplasms (cancer), which is in contrast with…
💬 14:22 Disease prevention, health promotion and health protection fall under the responsibility of municipa…
💬 18:4 In my model, health - defined broadly to include longevity and illness-free days in a given year
💬 18:6 Hence, the wage is positively correlated with the benefits of a reduction in lost time from the prod…
💬 18:7 First, an increase in the stock of health lowers the prob- ability of illness but has no impact on e…
💬 19:1 Some suggest that this may be a more relevant indicator to judge the impact of medical care as advan…
💬 19:2 These are both imaging tools that allow clinicians to diagnose prob- lems such as cancers, cardiovas…
💬 21:6 how they experience symptoms of illness, pain, and worries about their health and whether or not they judge their problems to be...sufficient...to seek professional help.
💬 21:7 More specific measures should relate to a particular condition, type of service or practitioner, or should be linked in an episode of illness. Such measures could be related more logically to the explanatory structure of the model, and might provide a more complete and understandable analysis. While such explicit measures are, in many ways, likely to be more informative, the more global ones still have a role to play.
💬 21:8 illness,pain, and worries about their health and whether or not they judge their problems to be of sufficient importance…
💬 21:9 episodeofillness.AlsoaddedinPhase2 was
💬 21:14 Healthbeliefsareattitudesv,alues,and shouldbeaddedtopredisposincgharacteris-knowledgethatpeoplehave…

💬 22:1 Solid line indicates course of illness without care; dotted line, course of illness with care to be…
💬 22:2 We need to know a great deal more about the course of illness with and without alternative methods of care.
💬 24:11 Co-payments or other forms of user charges serve a similar regressive purpose, weakening the link be…
💬 30:1 The transmission by physicians of information on diagnosed illnesses and prescribed drugs to local s…
💬 31:1 In a 2001 survey, 89 percent of adult Swedes agreed that individuals should not be able to receive f…
💬 38:1 The need component refers to illlnes level, which is the most immediate cause of health service use.
💬 38:3 Data on perceived need for care might comprise perceived health status, symptoms of illness, and disability.
💬 39:1 Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.
💬 40:5 The expected course ofthis type ofdisease, and hence the person's ex- pected level of health over ti…
💬 40:6 In one case, the disease is self-limiting in the sense that as time passes the person's health statu…
💬 46:1 “Illness ... is a feeling, an experience of unhealth which is entirely personal, interior to the per…
💬 47:6 . Medi- cal services, apart from preventive services, afford satisfaction only in the event of illne…

Linked Codes:
← assoc — ● Treatment

Groups:
Flows and abstractions   Flows and abstractions - core

Comment:
> Illness is a reduction in wellness. It is marked by a deviation from a baseline value, caused by an external event. The risk of illness is a function of factors endogenous and exogenous to the individual Person, but the precipitating event is essentially stochastic.

● Information

Used In Documents:
9 Sweden - HiT Report   14 Netherlands - HiT Report   30 Rochaix: State autonomy, policy paralysis   32 Tuohy: Dynamics of a changing health sphere

Quotations:
💬 9:4 Patient pathway Sweden
💬 14:7 This has meant fundamental changes in the roles of patients, insurers, providers and the government.…
💬 30:1 The transmission by physicians of information on diagnosed illnesses and prescribed drugs to local s…
💬 32:7 Similarly, different mixes of instruments imply different flows and costs of information. In the hea…
💬 32:8 Market-based instruments are information intensive. The purchaser must be able to write a specific c…

Groups:
Flows and abstractions   Flows and abstractions - core

Comment:
> Information is a package of data (i.e., a message) that flows between actors to improve knowledge and understanding. There are several key forms of information: description of patient condition and history, administrative scheduling of consultations, activity reports for payment purposes and particulars of insurance agreements and contracts.

Payment

Used In Documents:
1 HiT Template 2 Switzerland HiT report 3 Germany - HiT Report 6 Norway - HiT Report 24 Evans: Fellow travelers on a contested path 26 Quinn: The 8 Basic Payment Methods in Halth Care 37 Paris: Health Systems Institutional C.pdf 41 Paris:Health Systems Institutional C.pdf

Quotations:
- 1:4 Payment mechanisms
- 2:11 Financial flows are fragmented and split between different government levels and different social in…
- 2:13 Fee-for-service is the dominant method of provider payment in Switzerland. The tariffs for ambulator…
- 2:16 Owners of health care institutions are responsible for managing capital investments and, since the i…
- 2:23 Since the year 2000, numerous reforms have been made, which have optimized the MHI system, changed t…
- 3:9 Sickness funds pay for health care providers, with hospitals and physicians in ambulatory care (just…
- 3:10 Payment for ambulatory care is subject to predetermined price schemes for each profession (one for S…
- 6:25 In 2011, physicians employed by the RHAs earned NKr 63 300 (€8168) per month on average (including c…
- 24:7 Who gets care, who pays, who gets paid
- 24:9 But whatever the motivation, for good or from greed, more expenditure always means more income for s…
- 26:1 Payment methods are distinct from payment levels. Although payment methods certainly affect growth i…
- 37:13 All countries (with the exception of Mexico and Turkey) have implemented policies to protect populat…
- 41:20 Predominant modes of physician payment 94. Fee-for-service is the predominant mode of payments for p…
- 41:21 In Finland, most doctors working in municipal services are salaried employees. In some centres, pati…
- 41:22 Payment of hospitals for acute inpatient care 101. Most OECD countries use a mix of payment arrangem…
- 41:23 Payments per case/diagnosis related groups, payments per procedure/service and per diem all directly…

Groups:
Flows and abstractions Flows and abstractions - core

Comment:
> Payment is a flow of funds between actors. It essentially depletes the financial resources of the sender, and augments the resources of the recipient. It includes out-of-pocket tranfsers made by individual Person, and various forms of transfer by government or commercial firms.
>
> Merged comment from Funding on 2016-10-18, 11:29 AM
>
> Flow of money

Treatment

Used In Documents:
8 Denmark - HiT Report 18 Grossman: The human capital model 24 Evans: Fellow travelers on a contested path 38 Aday: A framework for the study of a.pdf 40 Donabedian: Quality, cost, and health an.pdf 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:

8:10 Many actors are involved in rehabilitation care within the health care sector, the social sector, th…

18:2 The distinction between health as an output or an object of choice and medical care as an input had n…

24:7 Who gets care, who pays, who gets paid

38:2 Types of care utilization: type, site, and curative, chronic or custodial.

40:3 The definition and measurement of health status developed above can be employed to examine the relat…

47:1 adaptations to the existence of uncertainty in the incidence of dis- ease and in the efficacy of tre…

47:7 These expectations are relevant because medical care belongs to the category of commodities for whic…

Linked Codes:

— assoc → ● Illness

Groups:

Flows and abstractions Flows and abstractions - core

Comment:

> Treatment is an episodic flow of resources from professional clinical providers of various types. It is intended to mitigate the adverse effects of illness on a Person. There are several types of treatment, often related to the special skill and technical resources of a particular provider. In many illnesses, multiple treatments are provided as a sequence following a "patient pathway."

Basic themes – associated with Person

Codes

Report created by Neil McEvoy on Jan 22, 2018

• illness follows a unique trajectory

Used In Documents:
38 Aday: A framework for the study of a.pdf 40 Donabedian: Quality, cost, and health an.pdf

Quotations:
38:1 The need component refers to illlnes level, which is the most immediate cause of health service use.
40:2 We include future expected health in our assessment of a person's health status by taking the sum ov…

Groups:
Basic themes Basic themes - associated with people

Comment:
> For every Person, each illness follows a trajectory of impairment over time. In the first instance, every illness has a charactistic trajectory observed reported in the literature. It is modulated in particular by the effects of any treatments received.
>
> For representation, the trajectory may be stylized to a limited set of trends, distinguished by magnitude, dynamic shape and duration.

• Illness incidence a function of person's age and history

Used In Documents:
10 United Kingdom - HiT Report 18 Grossman: The human capital model 50 Vos: Global Burden of Disease Study 2016

Quotations:
10:13 These adverse incidents contributed to death in 8% of cases. 4 Currently an increase in the number o…
18:7 First, an increase in the stock of health lowers the prob- ability of illness but has no impact on e…
50:1 The GBD study provides a standardised analytical approach for estimating incidence, prevalence, and…

Groups:
Basic themes Basic themes - associated with people

Comment:
> Several endogenous factors influence the occurrence of illness at the level of the individual. Thes include socio economic status, particularly as that factor relates to the larger determinants of health, including education and employment. Of particular note, factors such smoking, alcohol and opioid use, dietary choices and driving behaviour may contribute to the risk of illness.

• illness reduces illness-free days, modifes longevity, wellness.

Used In Documents:

18 Grossman: The human capital model 38 Aday: A framework for the study of a.pdf 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
18:4 In my model, health - defined broadly to include longevity and illness-free days in a given year
18:5 I have just shown that length of life is determined as the outcome of an iterative process in which…
38:2 Types of care utilization: type, site, and curative, chronic or custodial.
47:11 To recall what has already been said in Section I, there are two kinds of risks involved in medical…

Groups:
Basic themes Basic themes - associated with people

Comment:
> Illness impairs wellness. This reduction is an essential mechanism in healthcare.

---

incidence determined by illness type and prevalence, social factors

Used In Documents:
10 United Kingdom - HiT Report 38 Aday: A framework for the study of a.pdf

Quotations:
10:12 Reflecting on differences in health outcomes in England measured in terms of life expectancy and dis…
38:1 The need component refers to illlnes level, which is the most immediate cause of health service use.

Groups:
Basic themes Basic themes - associated with people

Comment:
> Several exogenous properties of the overall social context of a healthcare system contribute to the probability of an individual encountering an illness. These social determinants of health include education, housing, environmental and employments conditions. It is assumed that these factors are beyond the control of any individual person.
>
> The impact of these determinants varies among different illnesses and diseases.

Person chooses based on price, affordability

Used In Documents:
8 Denmark - HiT Report 37 Paris: Health Systems Institutional C.pdf 41 Paris:Health Systems Institutional C.pdf 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
8:24 Since 1973, residents over the age of 15 have been able to choose between two coverage options in th…
37:6 Naturally, consumer choice of insurer is a pre-condition for real competition in health insurance ma…
41:7 Consumer choice and competition between health insurers offering basic primary health care coverage…
47:12 As a basis for the analysis, the assumption is made that each individ- ual acts so as to maximize th…
47:14 The choice among these alternatives in any given case depends on the degree of difficulty consumers…

Groups:

Basic themes   Basic themes - associated with people

Comment:

A person who has encounters an illness chooses whether to seek treatment based on the degree of impairment of normal function, on the financial cost in out-of-pocket expense and on the utility cost in time to seek care. Out-of-pocket expense is the gap between total cost of treatment and and the amounts paid by any insurance coverage in force at the time.

This choice mechanism is a fundamental modifier of the essential mechanism of Treatment delivery.

Person encounters illness

Used In Documents:

9 Sweden - HiT Report   12 Belgium - HiT Report   18 Grossman: The human capital model   21 Andersen: Revisiting the behavioral model   47 Arrow: Uncertainty and the welfare ec.pdf   50 Vos: Global Burden of Disease Study 2016

Quotations:

9:4 Patient pathway Sweden
9:12 The number of patients seeking acute care
12:1 Patient pathway Belgium
18:4 In my model, health - defined broadly to include longevity and illness-free days in a given year
21:11 Some efforts have been made to integrate elements of the behavioral model with elements of the well-known health beliefs model...to explain preventive care.
47:12 As a basis for the analysis, the assumption is made that each individ- ual acts so as to maximize th…
50:1 The GBD study provides a standardised analytical approach for estimating incidence, prevalence, and…

Groups:

Basic themes   Basic themes - associated with people

Comment:

The incidence of an illness in a population is expressed as risk at the level of an individual Person. It is represented as a stochastic event, primarily exogenous to the individual. The probability of the event is represented as a random selection from a given distribution.

These encounters as cumulative events constitute another essential mechanism in the dynamics of healthcare systems.

Person is born, ages and dies

Used In Documents:

2 Switzerland HiT report   6 Norway - HiT Report   8 Denmark - HiT Report   14 Netherlands - HiT Report   39 About WHO : Definition of Health.pdf

Quotations:

2:2 Like many western European countries, Switzerland faces an ageing population, with the ratio of olde…
6:33 given the increasing proportion of older people in the population, the increasing use of new technol…
8:20 While life expectancy for a newborn boy increased by 20 years over the last century, it rose by four…
14:19 The majority of the residents in nursing homes and residential homes are older than 80 years. Fig. 6…
39:1 Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.

Groups:
Basic themes   Basic themes - associated with people

Comment:

A person's lifetime extends from birth to death. Birth and death are stochastic events. Every person has a probability of survival that decreases primarily with time (age). This is one of the essential mechanisms that accounts for the dynamics of healthcare systems.

Merged comment from aging (action) on 2017-11-14, 3:16 PM

an element gets older.

• Person may become a clinician

Used In Documents:
2 Switzerland HiT report   8 Denmark - HiT Report   10 United Kingdom - HiT Report   14 Netherlands - HiT Report   16 Ireland - HiT Report

Quotations:
- 2:54 Reforms since the year 2000 have improved the MHI system, changed the financing of hospitals, streng…
- 2:55 4) research and training (tertiary education, training of non-physician health professionals).
- 2:56 The most important areas of legislative responsibility of the Confederation (as defined by the const…
- 2:57 Some of the most important federal laws are: (1) the Federal Health Insurance Law (KVG/LAMal), deter…
- 2:58 So far, projects or platforms have been initiated amongst others for the development of the e-health…
- 2:59 It aims to influence health policy developments and was – prior to the creation of the Swiss Institu…
- 2:60 Their main functions are similar to those of the medical associations and include responsibilities f…
- 2:61 Subsequently, in 2007, the new MedBG/LPMéd led to the standardization of federal training requireme…
- 2:62 Regulation of human resources in Switzerland distinguishes between three groups of health profession…
- 2:63 The new coordination bodies, including the Swiss University Conference, will coordinate cantonal and…
- 2:64 These professions are regulated just as any other professional education by the State Secretariat fo…
- 2:65 After successful specialization, doctors are legally bound to participate in continuous professional…
- 2:66 This is mostly because a large number of physicians move to Switzerland after having completed their…
- 2:67 As part of this plan, the number of training places is being increased, nursing qualifications are b…
- 2:68 In 2013, almost 3100 students started nursing studies, with about two thirds enrolling at a College…
- 8:21 Regarding human resources, the number of physicians is experiencing a slight increase but recruitmen…
- 10:11 In England, the total number of doctors working in the NHS was 140 897 in 2009 (132 683 WTE), which…
- 14:20 Fig. 5.4 and Fig. 5.5 show that the number of physicians and nurses per 1000 population has grown ra…
- 16:22 Human resources are a key issue for the future of the health care service. The Government is committ…

Groups:
Basic themes   Basic themes - associated with people

Comment:

> With some probability, a person may make a career choice to become a clinician, an event that is relevant in the Provision Network theme.

Person may change employment

Used In Documents:

8 Denmark - HiT Report 12 Belgium - HiT Report

Quotations:

8:22 Self-rated health was also found to be correlated with educational level and employment status.
12:10 Before July 2007, in order to qualify for preferential reimbursement, a patient had to belong to a s…

Groups:

Basic themes Basic themes - associated with people

Comment:

> Among the important events during a life span, a person may change employment (joining or leaving) on a probabilistic basis; this may be relevant to availability of health insurance.

Person may purchase insurance

Used In Documents:

48 Geoffard: Incentive and selection effect.pdf

Quotations:

48:1 The demand for insurance stems from the desire by risk averse agents to equalize marginal utilitie…

Groups:

Basic themes Basic themes - associated with payers Basic themes - associated with people

Comment:

> In some jurisdictions, health insurance coverage may be available for purchase. The extent of available coverage varies with the jurisdiction and with the choice made by individual Person. The option to purchase and to renew is made periodically - typically each year.

Person reacts to treatment

Used In Documents:

9 Sweden - HiT Report

Quotations:

9:5 After the surgery, she will stay at the hospital until she is fully medically treated. The responsib…

Groups:

Basic themes Basic themes - associated with people

Comment:

> If a Person receives a Treatment the trajectory of her illness will be modified, based on the alignment and timing of the current Illness with the specific Treatment received.

Person seeks or is referred for treatment

Used In Documents:
6 Norway - HiT Report 9 Sweden - HiT Report 12 Belgium - HiT Report

Quotations:
6:10 Consumption of medicines has grown in recent years, though it is still substantially lower than in n…
9:4 Patient pathway Sweden
12:1 Patient pathway Belgium

Groups:
Basic themes Basic themes - associated with people

Comment:
> When a Person encounters an Illness, she may seek help in the form of Treatment from a Provider. In the case of an initial occurrence, this takes the form of a request for appointment - a type of Information flow. In the case of ongoing Treatments, the request may take the form of a referral, an Information message sent on behalf of a Person by another professional.
>
> This flow of Information is one of the fundamental mechanisms in the working of a healthcare system.

Treatments and timing modify patient's condition

Used In Documents:
9 Sweden - HiT Report

Quotations:
9:6 She can choose any hospital (public or private) she prefers if she does not want to go to the hospit…

Groups:
Basic themes Basic themes - associated with people

Comment:
> The Person's response to the treatment modifies her condition, based on degree of match between the treatment and the patient's condition and on any time delay betweeen the onset of the illness and the reaction to treatment received.

Waiting list grows/declines

Used In Documents:
8 Denmark - HiT Report 9 Sweden - HiT Report 25 Siciliani: Tackling excessive waiting times 37 Paris: Health Systems Institutional C.pdf 45 Bevan: Choice of providers and mutual.pdf

Quotations:
8:16 The reduction in waiting times, along with the waiting time guarantee and “extended free choice” of…
9:12 The number of patients seeking acute care
25:1 Waiting lists generally tend to be found in countries, which combine public health insurance, with z…
37:12 The information presented in Table 8 corresponds to institutional arrangements for health

care cover…
45:4 In the early 1990s, the Dutch government had effective systems for controlling prices, the number of…

Groups:
Basic themes Basic themes - associated with people Basic themes - associated with providers

Comment:
> A delay between the request for treatment and the delivery of that Treatment may modify the Person's response to the Treatment when it is received.
> Merged comment from Waiting time effect on 2017-11-14, 1:49 PM
>
> Waiting times occur when the instantaneous demand for treatment exceeds the capacity to provide treatment.
>
> Waiting time adds to the illness time of a person.

Basic themes – associated with Provision

Codes

Report created by Neil McEvoy on Jan 22, 2018

• Ability to pay determines access

Used In Documents:
3 Germany - HiT Report 8 Denmark - HiT Report 38 Aday: A framework for the study of a.pdf

Quotations:
3:13 the task of health insurance is “to maintain, restore or improve health...” (§ 1), to which end “car…
8:11 Special population groups have different kinds of access to the statutory health system. Recognized…
38:4 Two main themes regarding the access concept appear in the literature. Some researchers tend to equa…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> Payment for treatment is a factor in a Provider's acceptance of a request from of Person.

• Adjust capacity to realize goal

Used In Documents:
2 Switzerland HiT report 3 Germany - HiT Report 6 Norway - HiT Report 8 Denmark - HiT Report 13 France - HiT Report 33 Oliver: European health systems reform 35 Helderman: The rise of the regulatory state 45 Bevan: Choice of providers and mutual.pdf

Quotations:
2:1 Switzerland has a highly decentralized administrative and political structure, organized around thr…
2:6 The Swiss health system is highly complex, combining aspects of managed competition and “corporatism…
2:9 Cantons are responsible for securing health care provision for their populations, although they may…
2:15 The number of acute care hospitals decreased by about 50% between 2000 and 2013 and the number of be…
2:18 Responsibilities for the legislation, implementation and supervision of public health services are s…
2:24 One important trend across all reforms since 2000 (and even before that) has been a tendency towards…
3:3 Germany is a federal parliamentary republic consisting of 16 states (Länder), each of which has a c…
3:5 fundamental facet of the German political system – and the health care system in particular – is th…
6:3 The number of hospital beds has been declining since the late 1980s. The average length of hospital…
6:4 The number of practitioners in most health personnel groups, including physicians and nurses, has be…
8:1 The health system can be characterized as fairly decentralized, with responsibility for primary

and…
- 8:2 The five regions are, among other things, responsible for hospitals as well as for self-employed hea…
- 8:5 The number of hospital beds has declined since the early 1990s in the acute, long-term and psychiat…
- 8:7 Nurses constitute the largest group of health workers and the number of nurses has increased in rece…
- 13:4 Cutting across the traditional boundaries of health care, public health and health and social care s…
- 33:2 (1) governance at the national and local levels, including the prevailing electoral system and wheth…
- 35:1 Comparing these three different health-care systems suggests that it is indeed possible to identify…
- 45:3 An emphasis on patient choice for elective care. > A new reimbursement system, 'Payment by Results'…

Groups:
Basic themes   Basic themes - associated with events   Basic themes - associated with providers

Comment:
> Actor with governance responsibility periodically adjusts capacity of resouces among Providers. Adjustment is based on gap between existing production level and a target (goal) level, and on the relative priority of the actor's goal.

• Allocate resources to selected treatment

Used In Documents:
6 Norway - HiT Report   8 Denmark - HiT Report   16 Ireland - HiT Report   36 Smith: Leadership and governance in seven health systems   41 Paris:Health Systems Institutional C.pdf   44 Smith: The economics of health system.pdf

Quotations:
- 6:5 During the past decade, the government has launched a number of national public health programmes an…
- 8:6 A more recent trend is the merging of hospitals and the centralization of medical specialties, inclu…
- 16:3 primary care infrastructure is poorly developed and the services are fragmented with little teamwork…
- 36:1 Priority setting can be defined as a more or less systematic approach to distributing the availabl…
- 41:37 Resource allocation between regions and sectors of care does not always result from a decision- maki…
- 44:2 Groups influence allocation of resources

Groups:
Basic themes   Basic themes - associated with providers

Comment:
> Selected treatment determines resources required. Provider reduces resrouces and adds to the treatment package using a conversion from units of resource to units of treatment.

• Capacity related to funding

Groups:
Basic themes   Basic themes - associated with providers

Comment:

> The quantity of resources available to a Provider is determined by the funding available to the Provider, to the cost of each resource and to the allocations among the various resources.

- **Distinguish public or private provider**

Used In Documents:
8 Denmark - HiT Report 14 Netherlands - HiT Report 32 Tuohy: Dynamics of a changing health sphere 37 Paris: Health Systems Institutional C.pdf

Quotations:
8:23 The financing structure reflects attempts to control costs through global budgeting and upper limits…
14:8 The Dutch medical specialists traditionally have worked within the walls of a hospital for both inpa…
32:6 Actors whose influence is based on access to private finance must respond to the demands of owners o…
37:12 The information presented in Table 8 corresponds to institutional arrangements for health care cover…
37:17 The public/private mix of institutions delivering health care is often considered to be an important…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> Provider's status as Public or Private entity may be factor in the choices and allocations made. Goals differ.

- **Physician determines treatment**

Used In Documents:
8 Denmark - HiT Report 9 Sweden - HiT Report 12 Belgium - HiT Report 18 Grossman: The human capital model 32 Tuohy: Dynamics of a changing health sphere 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
8:8 The primary sector consists of private (self-employed) practitioners (GPs, specialists, physiotherap…
9:4 Patient pathway Sweden
12:1 Patient pathway Belgium
18:2 The distinction between health as an output or an object of choice and medical care as an input had n…
18:3 My approach uses the household production function model of consumer behavior [Becker (1965), Lancas…
32:7 Similarly, different mixes of instruments imply different flows and costs of information. In the hea…
47:9 Uncertainty as to the quality of the product is perhaps more intense here than in any other importan…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> Physician interprets care demanded by patient based on information provided.
> Merged comment from Physician determines treatment on 2016-10-18, 11:45 AM
> Physician diagnosis of patient condition/request determines the bundle of treatments to be provided. Note this distinguish the treatment plan (the demand for care as determined by provider) from the need (as indicated in request by patient).

Physician restricts referral - gatekeeping

Used In Documents:
6 Norway - HiT Report 8 Denmark - HiT Report 9 Sweden - HiT Report 12 Belgium - HiT Report 13 France - HiT Report 14 Netherlands - HiT Report 41 Paris:Health Systems Institutional C.pdf

Quotations:
6:6 Primary care is provided at the municipal level, mostly by self-employed physicians and as part of m…
8:8 The primary sector consists of private (self-employed) practitioners (GPs, specialists, physiotherap…
9:4 Patient pathway Sweden
12:2 GPs do not serve a gatekeeping role in Belgium.
13:11 From the late 1990s, GPs have gained a major role in the coordination of care with the implementatio…
14:9 In the field of primary care, the general practitioner (GP) plays the role of gatekeeper; patients n…
41:28 Gate-keeping 124. To encourage appropriate use of health services, more and more countries have been…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> Where gatekeeping exists by regulation, requests to specialist physicians are restricted to primary care physicians.

Provider delivers treatments as bundle

Used In Documents:
8 Denmark - HiT Report 10 United Kingdom - HiT Report

Quotations:
8:10 Many actors are involved in rehabilitation care within the health care sector, the social sector, th…
8:13 Other initiatives include the introduction of national clinical pathways for cancer and heart diseas…
10:1 The GP is seen as the focal point for all primary care services in England; however, primary care is…
10:14 Different examples of patient pathways are discussed in the sections that follow, particularly those…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> For a given illness a Provider may choose a nember of Treatments which are to be delivered in sequence, and possibly by other Providers. This entails the exchange of information among providers both to coordinate delivery and to facilitate ongoing updating of patient information. In bundle of treatments (beyond simple physician visit) each treatment is provided by one or more types of provider. Low grade illnesses are provided by primary care and long-term care if combined with other person attributes.

Provider reacts to request by placing person in queue, or rejecting request

Used In Documents:

9 Sweden - HiT Report   25 Siciliani: Tackling excessive waiting times

Quotations:
- 9:4 Patient pathway Sweden
- 25:4 Attributes of illness include severity, benefit of care, need, urgency and decay rate of disease.

Groups:
Basic themes   Basic themes - associated with providers

Comment:
> Providers initiate the delivery of Treatment on the basis of patient factors such as severity of illness and urgency of care. It may also include consideration of source of payment, including referral source and private insurance coverage. If sufficient capacity is not available immediately, Persons not in need of immediate treatment are assigned to a waiting status.
>
> Providers reject requests from Persons whose illness does not meet clinical criteria for type of care by the specific Provider, or who do to meet payment requirements.

• Providers coordinate care

Used In Documents:
9 Sweden - HiT Report   12 Belgium - HiT Report   13 France - HiT Report   41 Paris:Health Systems Institutional C.pdf

Quotations:
- 9:4 Patient pathway Sweden
- 9:21 Seven overall themes or areas have guided new initiatives since 2000: • continued specialization and…
- 12:11 Partly as a result of the lack of referral structure between different types of hospitals in Belgium…
- 13:11 From the late 1990s, GPs have gained a major role in the coordination of care with the implementatio…
- 41:35 Co-ordination of care 190. Questions 63 to 67 collected information on different aspect of care co-o…

Groups:
Basic themes   Basic themes - associated with providers

Comment:
> Providers exchange information in the form of patient data and scheduling requests when overall care requires sequential treatment by more that one Provider.

• Providers have privileged information

Used In Documents:
32 Tuohy: Dynamics of a changing health sphere   44 Smith: The economics of health system.pdf   47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
- 32:7 Similarly, different mixes of instruments imply different flows and costs of information. In the hea…
- 44:1 The characteristics of health care have necessitated signi cant adaptations of the traditional econo…
- 44:3 Concumer markets do not solve social optimality problems.
- 47:8 The physician is relied on as an expert in certifying to the existence of illnesses and injuries for…

Groups:
Basic themes   Basic themes - associated with providers

Comment:

> Providers' skills include the knowledge to interpret (diagose) clinical symptoms and to associate those findings with recommendations (prescriptions) for Treatment. As parties to the interactions of clinical care and of payment determination, Providers exercise authority and power asymmetrically.

● Provides treatment subject to available capacity

Used In Documents:
12 Belgium - HiT Report · 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
12:12 However, the total number of hospital beds did not decrease as desired by the government, which led…
47:10 In competitive theory, the supply of a commodity is governed by the net return from its production c…

Groups:
Basic themes · Basic themes - associated with providers

Comment:

> Providers use available resources to produce Treatments according to diagnosis of Illness and prescription of Treatment. If capacity has been exhausted, Treatment is not produced.
>
> This constraint is an essential mechanisms in healthcare delivery.

● Recruit and retain health professionals

Used In Documents:
2 Switzerland HiT report · 6 Norway - HiT Report · 12 Belgium - HiT Report · 14 Netherlands - HiT Report · 41 Paris:Health Systems Institutional C.pdf

Quotations:
2:44 Regulation of human resources in Switzerland distinguishes between three groups of health profession…
6:19 The Ministry of Health is responsible for the planning of human resources for health. The Directorat…
6:20 In 2010, at 407 physicians per 100 000 inhabitants, Norway had the highest physician coverage among…
12:4 The overall number of practising physicians, defined as a physician having provided more than one me…
12:5 it obliges human resources management departments to spend substantial amount of time and energy in…
14:5 The Dutch health care workforce is large and growing. About 7% of the population is working in the h…
41:31 This part of the questionnaire sought to assess the level of autonomy of hospital managers hold in t…

Groups:
Basic themes · Basic themes - associated with providers

Comment:

> Capacity is limited by financial resources with which to purchase them, and with the available supply of physical and human resources. This include recruitment of clinicians -- physicians, nurses and allied health professionals.

- **Replace inpatient care with ambulatory care.**

Used In Documents:
8 Denmark - HiT Report 12 Belgium - HiT Report

Quotations:
8:25 The quality of care for chronic conditions can be examined by looking at avoidable hospital admissio…
12:13 Health care is provided by public health services, independent ambulatory care professionals, indepe…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> Providers may choose among different courses of Treatment subject to professional beliefs and technical feasibility.

- **Treatment allocated according to insurance type**

Used In Documents:
9 Sweden - HiT Report 16 Ireland - HiT Report

Quotations:
9:7 If she wants to jump any waiting list she can access a private provider and pay for her treatment ou…
16:2 a key public perception has continued to be that there are inequities in access to treatment both in…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> Private insurance influences priority of patient in waiting list.

- **Treatment specific to type of provider**

Used In Documents:
9 Sweden - HiT Report 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
9:4 Patient pathway Sweden
47:9 Uncertainty as to the quality of the product is perhaps more intense here than in any other importan…

Groups:
Basic themes Basic themes - associated with providers

Comment:
> Providers delivery certain types of care. Primary care physicians provider first encounter care in the community. Specialist provide treatments in hospitals and ambulatory clinics, including diagnostic and therapeutic treatments. Pharmacy firms provide pharmaceuticals on the direction of physicians.

Waiting list grows/declines

Used In Documents:
8 Denmark - HiT Report 9 Sweden - HiT Report 25 Siciliani: Tackling excessive waiting times 37 Paris: Health Systems Institutional C.pdf 45 Bevan: Choice of providers and mutual.pdf

Quotations:
- 8:16 The reduction in waiting times, along with the waiting time guarantee and “extended free choice” of…
- 9:12 The number of patients seeking acute care
- 25:1 Waiting lists generally tend to be found in countries, which combine public health insurance, with z…
- 25:4 Attributes of illness include severity, benefit of care, need, urgency and decay rate of disease.
- 37:12 The information presented in Table 8 corresponds to institutional arrangements for health care cover…
- 45:4 In the early 1990s, the Dutch government had effective systems for controlling prices, the number of…

Groups:
Basic themes Basic themes - associated with people Basic themes - associated with providers

Comment:
> A delay between the request for treatment and the delivery of that Treatment may modify the Person's response to the Treatment when it is received.
> Waiting times occur when the instantaneous demand for treatment exceeds the capacity to provide treatment.

Basic themes – associated with Payment

Codes

Report created by Neil McEvoy on Jan 22, 2018

● Actors may compete

Used In Documents:
14 Netherlands - HiT Report 24 Evans: Fellow travelers on a contested path 28 Okma: Managed competition for Medicare 29 Okma: Swiss and Dutch "consumer-driven health care" 32 Tuohy: Dynamics of a changing health sphere 37 Paris: Health Systems Institutional C.pdf 41 Paris:Health Systems Institutional C.pdf 44 Smith: The economics of health system.pdf 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:
14:2 The reform introduced managed competition supervised by independent bodies. The health insurers, the…
24:8 The Dutch article raises the same question when it reports that the maximum spread among flat-rate p…
28:4 Four key points emerge from the Dutch experience. First, com- petition has not sharply slowed the ra…
28:5 The myth that competition has been key to cost containment in the Netherlands has obscured a crucial…
29:1 First, cost-conscientious and well-informed consumers who are mandated to take out health insurance…
29:2 res- ponding to that pressure, (competing) health insurers will act as prudent buyers of patient-fri…
32:2 In health care such mechanisms are typically threefold: the market, based on voluntary exchange; hie…
37:5 Policy analysts and economists have produced a large body of literature on the respective advantages…
37:7 Market structure is another important feature for competition. The number of plans a consumer typica…
41:7 Consumer choice and competition between health insurers offering basic primary health care coverage…
41:26 User choice and competition among providers 118. Health systems vary according to the extent to whic…
44:1 The characteristics of health care have necessitated signi cant adaptations of the traditional econo…
44:4 In practice the organizational aspects of a health system are often the result of historical acciden…
44:5 Regulation required
47:3 ealth, which I propose to discuss. The focus of discussion will be on the way the operation of the m…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> Competition among actors may occur, depending on regulations and structures in place. Competition may occur between providers in meeting demand from Persons or from Insurance Firms or Government. Similarly, competition may occur among Insurance firms in meeting demand for personal health insurance.

Buyer adjusts amount requested

Groups:
Basic themes Basic themes - associated with payers

Comment:
> This is one leg of a market exchange. In its simplest form, the buyer pays for all services provided by the Provider. In a more nuanced version, the buyer allocates a portion of the purchased services to each agreed Provider.

Constrains choices

Used In Documents:
41 Paris:Health Systems Institutional C.pdf

Quotations:
41:6 Regulation of health insurance markets in countries with multiple insurance funds 21. Countries with…
41:29 Regulation of the supply of physicians 146. The regulation of physicians supply was essentially appr…
41:30 Regulation of hospital supply and of the diffusion of high-cost medical technologies 158. The regula…
41:32 Prices paid by third-party payers are most often set or negotiated at the central level (Table 26).…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> A Payer may pay only for certain treatments deliverd by a Provider. This places a limit on the type of treatments provided under terms of insurance plans.

Contrains cost

Used In Documents:
6 Norway - HiT Report 13 France - HiT Report 41 Paris:Health Systems Institutional C.pdf

Quotations:
6:18 The focus of health care reforms has seen shifts over the past four decades. During the 1970s the fo…
13:14 The main objectives of the reforms to the health care system of the last decade were to contain SHI…
41:38 Definition of health care budget and pressure for cost-containment 208. Information on the nature of…
41:39 The use of health technology assessment 216. The survey intended to collect a minimum set of informa…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> A Payer may pay only up to a certain amont of funding for treatments deliverd by a Provider. This places a limit on the volume of treatments provided under terms of insurance plans.

- **Cost of resources related to price level**

Used In Documents:
3 Germany - HiT Report 24 Evans: Fellow travelers on a contested path 45 Bevan: Choice of providers and mutual.pdf

Quotations:
3:17 While expenditure per bed and day has continued to rise, expenditure per case actually declined in t…
3:18 whereas the sickness funds pay for operating costs, including those associated with salaries, the pr…
24:10 Cost control thus involves modifying physicians' behavior as much as or more than limiting their inc…
45:3 An emphasis on patient choice for elective care. > A new reimbursement system, 'Payment by Results'…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> Costs of resources used by Provider, and therefore the prices that must by paid by Payer is related to price levels in the economy at large. They are exogenous to these actors.

- **Everyone pays taxes**

Used In Documents:
16 Ireland - HiT Report

Quotations:
16:1 These reforms aim to make the system more primary care driven. The reforms, in part, were made possi…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> All persons pay taxes. This is of consequence if healthcare funded by government revenues.

- **Expectation of population influences allocation**

Used In Documents:
32 Tuohy: Dynamics of a changing health sphere 36 Smith: Leadership and governance in seven health systems

Quotations:
32:5 In very broad terms, state actors function within systems in which those in command ultimately are d…
32:13 Canadian Medicare bears the marks of its birth in the 1960s, an era of economic growth, high public…
32:14 A majority government in its third succes- sive term had not only the consolidated authority but als…
36:1 Priority setting can be defined as a more or less systematic approach to distributing the availabl…

Groups:
Basic themes Basic themes - associated with payers

Comment:

> Since government derives its power from the electorate, the choices exercised by government are influenced by the estimated reaction of voters.

Government/state may pay providers

Used In Documents:

10 United Kingdom - HiT Report 16 Ireland - HiT Report 47 Arrow: Uncertainty and the welfare ec.pdf

Quotations:

10:2 The stated objective of the introduction of the NHS was to create equitable access to health care by…
16:23 The Irish health care system remains predominantly tax funded. In 2006, 78.3% of total health expend…
47:13 The moral hazard. The welfare case for insurance policies of all sorts is overwhelming. It follows t…

Groups:

Basic themes Basic themes - associated with payers

Comment:

> Payment by government is an available option available by the state.

Healthcare expenditure related to economic growth

Used In Documents:

16 Ireland - HiT Report

Quotations:

16:1 These reforms aim to make the system more primary care driven. The reforms, in part, were made possi…
16:24 If expenditure as a proportion of gross national product (GNP), rather than GDP is used1 then Irelan…

Groups:

Basic themes Basic themes - associated with payers

Comment:

> Overall economic growth is a determinant of the amount of government revenues allocated to healthcare.

---

insure healthcare expenses

Used In Documents:

16 Ireland - HiT Report 24 Evans: Fellow travelers on a contested path 44 Smith: The economics of health system.pdf 48 Geoffard: Incentive and selection effect.pdf

Quotations:

16:1 These reforms aim to make the system more primary care driven. The reforms, in part, were made possi…
24:8 The Dutch article raises the same question when it reports that the maximum spread among flat-rate p…
44:3 Concumer markets do not solve social optimality problems.
48:1 The demand for insurance stems from the desire by risk averse agents to equalize marginal utilitie…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> Insurance by a third party, whether government, sickness funds or commercial insureance firms, is a basic mechanism in healthcare systems.

• insurer constrains treatment

Used In Documents:
41 Paris:Health Systems Institutional C.pdf 45 Bevan: Choice of providers and mutual.pdf

Quotations:
41:34 Regulation and monitoring of health provider activity 184. Several countries with modes of payment t…
45:4 In the early 1990s, the Dutch government had effective systems for controlling prices, the number of…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> Insurer may set limits to type and volume of services included in the payment agreement

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• Person may pay provider out-of-pocket

Used In Documents:
9 Sweden - HiT Report 24 Evans: Fellow travelers on a contested path 29 Okma: Swiss and Dutch "consumer-driven health care"

Quotations:
9:4 Patient pathway Sweden
9:7 If she wants to jump any waiting list she can access a private provider and pay for her treatment ou…
9:13 Pharma care
24:7 Who gets care, who pays, who gets paid
29:1 First, cost-conscientious and well-informed consumers who are mandated to take out health insurance…

Groups:
Basic themes Basic themes - associated with payers

Comment:
> Individuals pay out-of-pocket for portions of the care when it is a necessary part of the care, and it is not covered by an insurance plan.

• Person may purchase insurance

Used In Documents:
48 Geoffard: Incentive and selection effect.pdf

Quotations:
48:1 The demand for insurance stems from the desire by risk averse agents to equalize marginal utilitie…

Groups:

Basic themes   Basic themes - associated with payers   Basic themes - associated with people

Comment:

> In some jurisdictions, health insurance coverage may be available for purchase either as replacement of or additional to existing publicly available insurance. The extent of available coverage varies with the jurisdiction and with the choice made by individual Person. The option to purchase and to renew is made periodically - typically each year.

• Price level is related to nominal growth

Groups:

Basic themes   Basic themes - associated with payers

Comment:

> Price levels change with changes in productivity in the larger economy.

• Seller adjusts price

Used In Documents:

45 Bevan: Choice of providers and mutual.pdf

Quotations:

45:6 This Act introduced a package of crucial major systemic reforms including choice among competing MHP…

Groups:

Basic themes   Basic themes - associated with payers

Comment:

> This is one leg of a market exchange. In its simplest form, the seller offers services at a given price, which the buyer may accept or reject, either in whole or in part.

• Social fund/Commercial insurer may pay providers

Used In Documents:

29 Okma: Swiss and Dutch "consumer-driven health care"   32 Tuohy: Dynamics of a changing health sphere   37 Paris: Health Systems Institutional C.pdf   45 Bevan: Choice of providers and mutual.pdf

Quotations:

29:2 res- ponding to that pressure, (competing) health insurers will act as prudent buyers of patient-fri…
32:6 Actors whose influence is based on access to private finance must respond to the demands of owners o…
37:10 Most OECD countries guarantee a high level of coverage for acute inpatient care and medical services…
45:6 This Act introduced a package of crucial major systemic reforms including choice among competing MHP…

Groups:

Basic themes   Basic themes - associated with payers

Comment:

> In regimes that permit or require mandatory or voluntary insurance, it is provided by private or corporatist organization.

Organizing themes

Codes

Report created by Neil McEvoy on Jan 22, 2018

● Delivers treatment

Comment:

> Provider transfers produced treatment as a one episode (of possibly many) to the Person who requested care. The treatment may include a link to future treatments in the form of an Information message.

8 Linked Codes:

← basic theme — ● Adjust capacity to realize goal

Linked Codes:
— basic theme → ● Delivers treatment
— basic theme → ● Interventions
— basic theme → ● Produces treatment

← assoc — ● Government

Linked Codes:
— assoc → ● Delivers treatment
— assoc → ● Triages patient requests

← assoc — ● Payment

Linked Codes:
— assoc → ● Delivers treatment

← basic theme — ● Provider delivers treatments as bundle

Linked Codes:
— basic theme → ● Delivers treatment

← basic theme — ● Providers coordinate care

Linked Codes:
— basic theme → ● Delivers treatment

← basic theme — ● Provides treatment subject to available capacity

Linked Codes:
— basic theme → ● Delivers treatment
— basic theme → ● Produces treatment

— theme of → ● Provision Network: providers delivering treatments

Linked Codes:
← theme of — ● Delivers treatment
← theme of — ● Diagnoses patient needs
← theme of — ● Produces treatment
← theme of — ● Triages patient requests

← **basic theme** — ● **Treatment specific to type of provider**

Linked Codes:
— basic theme → ● Delivers treatment

● Diagnoses patient needs

Comment:

> Provider (usually a physician) interpets the request for care, applying criteria as rules, to select the bundle of treatments that will be produced and delivered.

8 Linked Codes:

← **basic theme** — ● **Actor chooses based on values**

Linked Codes:
— basic theme → ● Diagnoses patient needs

← **basic theme** — ● **Distinguish public or private provider**

Linked Codes:
— basic theme → ● Diagnoses patient needs

← **basic theme** — ● **Person chooses based on price, affordability**

Linked Codes:
— basic theme → ● Diagnoses patient needs
— basic theme → ● Person encounters deterioration in condition

← **basic theme** — ● **Physician determines treatment**

Linked Codes:
— basic theme → ● Diagnoses patient needs

← **basic theme** — ● **Providers have privileged information**

Linked Codes:
— basic theme → ● Diagnoses patient needs

— **theme of** → ● **Provision Network: providers delivering treatments**

Linked Codes:
← theme of — ● Delivers treatment
← theme of — ● Diagnoses patient needs
← theme of — ● Produces treatment
← theme of — ● Triages patient requests

← **basic theme** — ● **Treatment allocated according to insurance type**

Linked Codes:
— basic theme → ● Diagnoses patient needs

← **basic theme** — ● **Waiting list grows/declines**

Linked Codes:
— basic theme → ● Diagnoses patient needs
— basic theme → ● Person responds to care
— basic theme → ● Triages patient requests

● Endogenous change

Comment:

> Changes of state that are caused by the activities among the elements internal to the system's context. These include the essential changes in patient condition associated with illness, treatment and recovery, the processes that providers use in scheduling care and in converting resources into treatments. They also include the adjustment that providers may make periodically to the allocation of resources.

6 Linked Codes:

— **theme of → ● Change Theme: how things change**

Linked Codes:
- ← theme of — ● Endogenous change
- ← theme of — ● Exogenous change
- ← theme of — ● Interventions
- ← theme of — ● Levels of change

← **basic theme — ● Conjuncture**

Linked Codes:
- — basic theme → ● Endogenous change

← **basic theme — ● Demographic change**

Linked Codes:
- — basic theme → ● Endogenous change
- — basic theme → ● Exogenous change

← **basic theme — ● Group change**

Linked Codes:
- — basic theme → ● Endogenous change

← **basic theme — ● Path dependence**

Linked Codes:
- — basic theme → ● Endogenous change

← **basic theme — ● Technological development**

Linked Codes:
- — basic theme → ● Endogenous change
- — basic theme → ● Exogenous change

● Exogenous change

Comment:

> Exogenous changes arise in the larger context on the one hand in the larger dynamics of society itself. Demographic change is among the most basic change influences. Birth, mortaltiy and migration rates directly influence the numbers of people requesting care, while other social determinants of health - education, housing, employment and environment - influence the incidence and prevalence of illness both positively or negatively. Large scale shifts in the economy influences funds available for allocation to healthcare, while changes in the political landscape such as when the governing mandate passes between parties and ideologies, or when people described as "dynamic policy actors"

6 Linked Codes:

— theme of → ● **Change Theme: how things change**

Linked Codes:
← theme of — ● Endogenous change
← theme of — ● Exogenous change
← theme of — ● Interventions
← theme of — ● Levels of change

← **basic theme** — ● **Demographic change**

Linked Codes:
— basic theme → ● Endogenous change
— basic theme → ● Exogenous change

← **basic theme** — ● **Dynamic policy actors**

Linked Codes:
— basic theme → ● Exogenous change

← **basic theme** — ● **Economic change**

Linked Codes:
— basic theme → ● Exogenous change

← **basic theme** — ● **Political climate changes for government**

Linked Codes:
— basic theme → ● Exogenous change

← **basic theme** — ● **Technological development**

Linked Codes:
— basic theme → ● Endogenous change
— basic theme → ● Exogenous change

● Interventions

Comment:
> Deliberate change of state in one or more system elements, initiated either endogenously or exogenously.

4 Linked Codes:
← **basic theme** — ● **Adjust capacity to realize goal**

Linked Codes:
— basic theme → ● Delivers treatment
— basic theme → ● Interventions
— basic theme → ● Produces treatment

← **basic theme** — ● **Authority centralizes/decentralizes**

Linked Codes:
— basic theme → ● Interventions

— **theme of** → ● **Change Theme: how things change**

Linked Codes:

← theme of — • Endogenous change
← theme of — • Exogenous change
← theme of — • Interventions
← theme of — • Levels of change

← basic theme — • Focus on sector

Linked Codes:
— basic theme → • Interventions

• Levels of change

Comment:

> This theme distinguishes three ways in which change occurs. Each is a mechanism involving activities that produce change in state; they differ in primarily in the entities of which the state is a property, and as a consequence the actors associated with the mechanism and the entities. The first level refers to changes that occur in the value of a property associated with a construct and relative to a goal; the second refers to the construct itself relative to an existing goal, and the third refers to new versions of the goal itself.

4 Linked Codes:

— theme of → • Change Theme: how things change

Linked Codes:
← theme of — • Endogenous change
← theme of — • Exogenous change
← theme of — • Interventions
← theme of — • Levels of change

← basic theme — • First level: change settings

Linked Codes:
— basic theme → • Levels of change

← basic theme — • Second level: change process

Linked Codes:
— basic theme → • Levels of change

← basic theme — • Third level: change strategy

Linked Codes:
— basic theme → • Levels of change

• Overall economy determines costs of services

Comment:

> The total cost of services is the sum of all payments made in relation to the provision of care. This includes amounts paid to providers directly, and amounts paid as premiums to administer insurance plans.

3 Linked Codes:

← basic theme — • Cost of resources related to price level

Linked Codes:
— basic theme → • Overall economy determines costs of services

— theme of → ● **Payments Exchange: actors agree to pay for treatments**

Linked Codes:
← theme of — ● Overall economy determines costs of services
← theme of — ● Payers determine prices and quantities through market mechanisms
← theme of — ● Payers flow funds in several forms
← theme of — ● Payers respond to competing pressures
← theme of — ● Various payers pay various providers

← **basic theme** — ● **Price level is related to nominal growth**

Linked Codes:
— basic theme → ● Overall economy determines costs of services

---

● Payers determine prices and quantities through market mechanisms

Comment:

> In a market mechanism, providers adjust the value of their products so that consumers will choose to purchase their product. In a market, there is more than one provider, and more that one consumer.

5 Linked Codes:

← **basic theme** — ● **Actors may compete**

Linked Codes:
— basic theme → ● Payers determine prices and quantities through market mechanisms

← **basic theme** — ● **Buyer adjusts amount requested**

Linked Codes:
— basic theme → ● Payers determine prices and quantities through market mechanisms

— **theme of** → ● **Payments Exchange: actors agree to pay for treatments**

Linked Codes:
← theme of — ● Overall economy determines costs of services
← theme of — ● Payers determine prices and quantities through market mechanisms
← theme of — ● Payers flow funds in several forms
← theme of — ● Payers respond to competing pressures
← theme of — ● Various payers pay various providers

← **basic theme** — ● **Person may purchase insurance**

Linked Codes:
— basic theme → ● Payers determine prices and quantities through market mechanisms
— basic theme → ● Person lives normal life
— basic theme → ● Various payers pay various providers

← **basic theme** — ● **Seller adjusts price**

Linked Codes:
— basic theme → ● Payers determine prices and quantities through market mechanisms

---

● Payers flow funds in several forms

Comment:

> Flow of funds is a fundamental mechansism of healthcare system activities. Funds (payments) flow in different forms from a financing agent to a provider.

11 Linked Codes:

← flows — • Block funding

Linked Codes:
— flows → • Payers flow funds in several forms

← flows — • Capitation payment

Linked Codes:
— flows → • Payers flow funds in several forms

← flows — • Diagnosis related

Linked Codes:
— flows → • Payers flow funds in several forms

← flows — • Fee for service

Linked Codes:
— flows → • Payers flow funds in several forms

← flows — • Health insurance

Linked Codes:
— flows → • Payers flow funds in several forms

← flows — • Out-of-pocket expense

Linked Codes:
— flows → • Payers flow funds in several forms

— theme of → • Payments Exchange: actors agree to pay for treatments

Linked Codes:
← theme of — • Overall economy determines costs of services
← theme of — • Payers determine prices and quantities through market mechanisms
← theme of — • Payers flow funds in several forms
← theme of — • Payers respond to competing pressures
← theme of — • Various payers pay various providers

← flows — • Per diem

Linked Codes:
— flows → • Payers flow funds in several forms

← flows — • Premium

Linked Codes:
— flows → • Payers flow funds in several forms

← flows — • Social/statutory insurance

Linked Codes:
— flows → • Payers flow funds in several forms

← **flows** — ● **Taxes**

Linked Codes:
— flows → ● Payers flow funds in several forms

● Payers respond to competing pressures

Comment:

> An action that tends to reduce the difference between two values. It is an available mechanism if the action is not constrained, and if there is a causal link between the input variable and the variable whose difference is to be reduced. Providers update where limited resources are allocated to types of care within their authority.

6 Linked Codes:

← **basic theme** — ● **Constrains choices**

Linked Codes:
— basic theme → ● Payers respond to competing pressures

← **basic theme** — ● **Contrains cost**

Linked Codes:
— basic theme → ● Payers respond to competing pressures

← **basic theme** — ● **Expectation of population influences allocation**

Linked Codes:
— basic theme → ● Payers respond to competing pressures

← **basic theme** — ● **Healthcare expenditure related to economic growth**

Linked Codes:
— basic theme → ● Payers respond to competing pressures

← **basic theme** — ● **insurer constrains treatment**

Linked Codes:
— basic theme → ● Payers respond to competing pressures

— **theme of** → ● **Payments Exchange: actors agree to pay for treatments**

Linked Codes:
← theme of — ● Overall economy determines costs of services
← theme of — ● Payers determine prices and quantities through market mechanisms
← theme of — ● Payers flow funds in several forms
← theme of — ● Payers respond to competing pressures
← theme of — ● Various payers pay various providers

● Person encounters deterioration in condition

Comment:

> This is one of the fundamental events that triggers the functioning of a healthcare system. Against a background of an otherwise normal life, during a person's lifetime, a person encounters an illness. The illness follows a natural course that modifies her probability of survival. Her illness-free days are reduced by the duration in days of the illness. Longevity may be influenced by an illness.

8 Linked Codes:

← basic theme — ● illness follows a unique trajectory

Linked Codes:
— basic theme → ● Person encounters deterioration in condition

← basic theme — ● Illness incidence a function of person's age and history

Linked Codes:
— basic theme → ● Person encounters deterioration in condition

← basic theme — ● illness reduces illness-free days, modifes longevity, wellness.

Linked Codes:
— basic theme → ● Person encounters deterioration in condition

← basic theme — ● incidence determined by illness type and prevalence, social factors

Linked Codes:
— basic theme → ● Person encounters deterioration in condition

— theme of → ● Life Course: healthy lives interrupted by illnesses

Linked Codes:
← theme of — ● Person encounters deterioration in condition
← theme of — ● Person lives normal life
← theme of — ● Person responds to care

← basic theme — ● Person chooses based on price, affordability

Linked Codes:
— basic theme → ● Diagnoses patient needs
— basic theme → ● Person encounters deterioration in condition

← basic theme — ● Person encounters illness

Linked Codes:
— basic theme → ● Person encounters deterioration in condition

← basic theme — ● Person seeks or is referred for treatment

Linked Codes:
— basic theme → ● Person encounters deterioration in condition
— basic theme → ● Person responds to care

● Person lives normal life

Comment:

> This is the background activity against which all other heatlhcare activities are conducted. A person's lifetime extends from birth to death with a probability of survival that decreases with time (age). Her baseline of illness free days at any time is the accumulated days to that time. Among the important events during a life span, a person may change employment (joining or leaving) on a probabilistic basis; this may be relevant to availability of health insurance. With a given probability, a person may also make a career choice to become a clinician, an event that is relevant in the Provision Network theme.

5 Linked Codes:

— theme of → ● **Life Course: healthy lives interrupted by illnesses**

Linked Codes:
← theme of — ● Person encounters deterioration in condition
← theme of — ● Person lives normal life
← theme of — ● Person responds to care

← **basic theme** — ● **Person is born, ages and dies**

Linked Codes:
— basic theme → ● Person lives normal life

← **basic theme** — ● **Person may become a clinician**

Linked Codes:
— basic theme → ● Person lives normal life

← **basic theme** — ● **Person may change employment**

Linked Codes:
— basic theme → ● Person lives normal life

← **basic theme** — ● **Person may purchase insurance**

Linked Codes:
— basic theme → ● Payers determine prices and quantities through market mechanisms
— basic theme → ● Person lives normal life
— basic theme → ● Various payers pay various providers

● Person responds to care

Comment:

> This is the activity that begins when the Person who has requested care received treatment in response. Reaction depends on the match between the treatment received and the illness experienced. The reaction also depends on any subsequent actions indicated in the Treatment, which may include requests (referrals) for further treatment, including acquiring and consuming pharmaceuticals.

6 Linked Codes:

— **theme of** → ● **Life Course: healthy lives interrupted by illnesses**

Linked Codes:
← theme of — ● Person encounters deterioration in condition
← theme of — ● Person lives normal life
← theme of — ● Person responds to care

← **basic theme** — ● **Patient pathway**

Linked Codes:
— basic theme → ● Person responds to care

← **basic theme** — ● **Person reacts to treatment**

Linked Codes:
— basic theme → ● Person responds to care

← **basic theme** — ● **Person seeks or is referred for treatment**

Linked Codes:
— basic theme → ● Person encounters deterioration in condition
— basic theme → ● Person responds to care

← **basic theme** — ● **Treatments and timing modify patient's condition**

Linked Codes:
— basic theme → ● Person responds to care

← **basic theme** — ● **Waiting list grows/declines**

Linked Codes:
— basic theme → ● Diagnoses patient needs
— basic theme → ● Person responds to care
— basic theme → ● Triages patient requests

● Produces treatment

Comment:

> Provider allocates and converts available resources to produce treatments. This includes immediate activities related to the request and diagnosis at hand, but it may also include activities that modify the processes and allocations, including improvement initiatives, budget refinements and human resources recruitment activities. This is the domain of operational and quality improvement.

8 Linked Codes:

← **basic theme** — ● **Adjust capacity to realize goal**

Linked Codes:
— basic theme → ● Delivers treatment
— basic theme → ● Interventions
— basic theme → ● Produces treatment

← **basic theme** — ● **Allocate resources to selected treatment**

Linked Codes:
— basic theme → ● Produces treatment

← **assoc** — ● **capacity**

Linked Codes:
— assoc → ● Produces treatment

← **basic theme** — ● **Capacity related to funding**

Linked Codes:
— basic theme → ● Produces treatment

← **basic theme** — ● **Provides treatment subject to available capacity**

Linked Codes:
— basic theme → ● Delivers treatment
— basic theme → ● Produces treatment

— **theme of** → ● **Provision Network: providers delivering treatments**

Linked Codes:
← theme of — ● Delivers treatment
← theme of — ● Diagnoses patient needs
← theme of — ● Produces treatment
← theme of — ● Triages patient requests

← **basic theme** — ● **Recruit and retain health professionals**

Linked Codes:
— basic theme → ● Produces treatment

← **basic theme** — ● **Replace inpatient care with ambulatory care.**

Linked Codes:
— basic theme → ● Produces treatment

● Triages patient requests

Comment:
> This is the initial response to a request received from a Person. The Provider assesses eligibility on financial and clinical grounds, determining if and when the treatment processes will be initiated.

6 Linked Codes:

← **basic theme** — ● **Ability to pay determines access**

Linked Codes:
— basic theme → ● Triages patient requests

← **assoc** — ● **Government**

Linked Codes:
— assoc → ● Delivers treatment
— assoc → ● Triages patient requests

← **basic theme** — ● **Physician restricts referral - gatekeeping**

Linked Codes:
— basic theme → ● Triages patient requests

← **basic theme** — ● **Provider reacts to request by placing person in queue, or rejecting request**

Linked Codes:
— basic theme → ● Triages patient requests

— **theme of** → ● **Provision Network: providers delivering treatments**

Linked Codes:
← theme of — ● Delivers treatment
← theme of — ● Diagnoses patient needs
← theme of — ● Produces treatment
← theme of — ● Triages patient requests

← **basic theme** — ● **Waiting list grows/declines**

Linked Codes:

— basic theme → ● Diagnoses patient needs
— basic theme → ● Person responds to care
— basic theme → ● Triages patient requests

● Various payers pay various providers

Comment:

> Funds flow through different channels from financing agent to provider for various types of care.

8 Linked Codes:

← basic theme — ● Everyone pays taxes

Linked Codes:
— basic theme → ● Various payers pay various providers

← basic theme — ● Government/state may pay providers

Linked Codes:
— basic theme → ● Various payers pay various providers

← basic theme — ● insure healthcare expenses

Linked Codes:
— basic theme → ● Various payers pay various providers

— assoc → ● Payer

Linked Codes:
← assoc — ● Various payers pay various providers

— theme of → ● Payments Exchange: actors agree to pay for treatments

Linked Codes:
← theme of — ● Overall economy determines costs of services
← theme of — ● Payers determine prices and quantities through market mechanisms
← theme of — ● Payers flow funds in several forms
← theme of — ● Payers respond to competing pressures
← theme of — ● Various payers pay various providers

← basic theme — ● Person may pay provider out-of-pocket

Linked Codes:
— basic theme → ● Various payers pay various providers

← basic theme — ● Person may purchase insurance

Linked Codes:
— basic theme → ● Payers determine prices and quantities through market mechanisms
— basic theme → ● Person lives normal life
— basic theme → ● Various payers pay various providers

← basic theme — ● Social fund/Commercial insurer may pay providers

Linked Codes:
— basic theme → ● Various payers pay various providers

Global themes

Codes

Report created by Neil McEvoy on Jan 22, 2018

● Change Theme: how things change

Comment:

> The change theme distills the dynamics of healthcare and the means by which they occur.
>
> Changes are distinguished not only in magnitude by also in their level, the extent to which they include or involve other actors and other parts of the system. Their source is also relevant; those arising outside the system reflect the context in which the healthcare system exists, while those arising within are a reflection of the nature of the healthcare system itself, of its reactions and responses to other events generated internally. Interventions are special cases of exogenous change in that they represent events - changes intentionally instigated by actors within the system. Finally _choice_ emerges as an important sub theme in the literature, relecting the human and organizational nature of the actors.

6 Linked Codes:

← theme of — ● Actor chooses based on values

Linked Codes:
— theme of → ● Change Theme: how things change

← theme of — ● Endogenous change

Linked Codes:
— theme of → ● Change Theme: how things change

← theme of — ● Exogenous change

Linked Codes:
— theme of → ● Change Theme: how things change

— theme of → ● Healthcare system

Linked Codes:
← theme of — ● Change Theme: how things change
← theme of — ● Life Course: healthy lives interrupted by illnesses
← theme of — ● Payments Exchange: actors agree to pay for treatments
← theme of — ● Provision Network: providers delivering treatments

← theme of — ● Interventions

Linked Codes:
— theme of → ● Change Theme: how things change

← theme of — ● Levels of change

Linked Codes:
— theme of → ● Change Theme: how things change

● Healthcare system

Comment:

A healthcare system exists in the context of other social and administrative systems systems in a country or region.

A healthcare system is described by three global themes that represent its structures and relationships. The first global theme represents the lifespans of a population, including birth, death and episodic encounters with illness and treatment. The second global theme represents the various providers of treatment and their collective behaviours in loosely formed networks. The third global theme represents the activities and behaviours of various actors - individuals, govenrment and firms - as they exchange funds with providers in exchange for the treatments provided.

A fourth global theme overlays describing the mechanisms of change and intervention that characterize the dynamics and causality of healthcare systems.

7 Linked Codes:

← theme of — ● Change Theme: how things change

Linked Codes:
— theme of → ● Healthcare system

← property — ● equity - financing

Linked Codes:
— property → ● Healthcare system

← property — ● goal

Linked Codes:
— property → ● Healthcare system

← theme of — ● Life Course: healthy lives interrupted by illnesses

Linked Codes:
— theme of → ● Healthcare system

← theme of — ● Payments Exchange: actors agree to pay for treatments

Linked Codes:
— theme of → ● Healthcare system

← theme of — ● Provision Network: providers delivering treatments

Linked Codes:
— theme of → ● Healthcare system

← property — ● quality

Linked Codes:
— property → ● Healthcare system

● Life Course: healthy lives interrupted by illnesses

Comment:

The Life Course global theme describes people as populations as they move collectively through various stages and states of wellness through their lives. As each individual person follows a life course from birth to death, her lifespan may be punctuated by episodes in which she may experience illness, and become a patient.

Depending on individual social and physiological circumstances, indviduals may chose to request the support and services of others in managing the effects of illness. Again depending on circumstances. these services influence the effects of illness and treatment on the patient's health status and on her recovery or demise.

15 Linked Codes:

← property — ● equity

Linked Codes:
— property → ● Life Course: healthy lives interrupted by illnesses

← flows to — ● Health insurance

Linked Codes:
— flows to → ● Life Course: healthy lives interrupted by illnesses
← flows — ● Payments Exchange: actors agree to pay for treatments

← property — ● health status

Linked Codes:
— property → ● Life Course: healthy lives interrupted by illnesses

— theme of → ● Healthcare system

Linked Codes:
← theme of — ● Change Theme: how things change
← theme of — ● Life Course: healthy lives interrupted by illnesses
← theme of — ● Payments Exchange: actors agree to pay for treatments
← theme of — ● Provision Network: providers delivering treatments

← property — ● incidence

Linked Codes:
— property → ● Life Course: healthy lives interrupted by illnesses

← flows — ● Information

Linked Codes:
— flows → ● Life Course: healthy lives interrupted by illnesses
— flows to → ● Payments Exchange: actors agree to pay for treatments
— flows to → ● Provision Network: providers delivering treatments

← assoc — ● Patient

Linked Codes:
— assoc → ● Life Course: healthy lives interrupted by illnesses
— assoc → ● Provision Network: providers delivering treatments

— flows → ● Payment

Linked Codes:
← flows — ● Life Course: healthy lives interrupted by illnesses
← flows — ● Payments Exchange: actors agree to pay for treatments
— flows to → ● Provision Network: providers delivering treatments

← **theme of** — ● **Person encounters deterioration in condition**

Linked Codes:
— theme of → ● Life Course: healthy lives interrupted by illnesses

← **theme of** — ● **Person lives normal life**

Linked Codes:
— theme of → ● Life Course: healthy lives interrupted by illnesses

← **theme of** — ● **Person responds to care**

Linked Codes:
— theme of → ● Life Course: healthy lives interrupted by illnesses

← **assoc** — ● **Population**

Linked Codes:
— assoc → ● Life Course: healthy lives interrupted by illnesses

← **property** — ● **prevalence**

Linked Codes:
— property → ● Life Course: healthy lives interrupted by illnesses

← **flows** — ● **Request/ referral**

Linked Codes:
— flows → ● Life Course: healthy lives interrupted by illnesses
— flows to → ● Provision Network: providers delivering treatments

← **flows** — ● **Treatment**

Linked Codes:
— flows → ● Life Course: healthy lives interrupted by illnesses
← flows — ● Provision Network: providers delivering treatments

---

● Payments Exchange: actors agree to pay for treatments

Comment:

> For some members of the population, healthcare costs are paid by a third party. There are many ways in which the payments are made. There may be limits on whose costs will be covered, and on which costs will be covered for those people.

14 Linked Codes:

← **property** — ● **expenditure**

Linked Codes:
— property → ● Payments Exchange: actors agree to pay for treatments

← **property** — ● **gdp**

Linked Codes:
— property → ● Payments Exchange: actors agree to pay for treatments

— flows → ● **Health insurance**

Linked Codes:
— flows to → ● Life Course: healthy lives interrupted by illnesses
← flows — ● Payments Exchange: actors agree to pay for treatments

— theme of → ● **Healthcare system**

Linked Codes:
← theme of — ● Change Theme: how things change
← theme of — ● Life Course: healthy lives interrupted by illnesses
← theme of — ● Payments Exchange: actors agree to pay for treatments
← theme of — ● Provision Network: providers delivering treatments

← flows to — ● **Information**

Linked Codes:
— flows → ● Life Course: healthy lives interrupted by illnesses
— flows to → ● Payments Exchange: actors agree to pay for treatments
— flows to → ● Provision Network: providers delivering treatments

← flows to — ● **Information: accountability**

Linked Codes:
— flows to → ● Payments Exchange: actors agree to pay for treatments
← flows — ● Provision Network: providers delivering treatments

← assoc — ● **insurance**

Linked Codes:
— assoc → ● Payments Exchange: actors agree to pay for treatments

← theme of — ● **Overall economy determines costs of services**

Linked Codes:
— theme of → ● Payments Exchange: actors agree to pay for treatments

← theme of — ● **Payers determine prices and quantities through market mechanisms**

Linked Codes:
— theme of → ● Payments Exchange: actors agree to pay for treatments

← theme of — ● **Payers flow funds in several forms**

Linked Codes:
— theme of → ● Payments Exchange: actors agree to pay for treatments

← theme of — ● **Payers respond to competing pressures**

Linked Codes:
— theme of → ● Payments Exchange: actors agree to pay for treatments

— flows → ● **Payment**

Linked Codes:
← flows — ● Life Course: healthy lives interrupted by illnesses
← flows — ● Payments Exchange: actors agree to pay for treatments
— flows to → ● Provision Network: providers delivering treatments

← **property** — • **productivity and labour rates**

Linked Codes:
— property → • Payments Exchange: actors agree to pay for treatments

← **theme of** — • **Various payers pay various providers**

Linked Codes:
— theme of → • Payments Exchange: actors agree to pay for treatments

---

• Provision Network: providers delivering treatments

Comment:

The Provision Network global theme describes the healthcare system from the perspecitve of the network of providers elements. The master theme distinguishes the ways in which the providers individually and collectively assess the requests for care (access), respond to the requests for care (demand), and organize to supply the treatment that consistute that care (supply).

supply of treatments describes how various providers construct and deliver the components of healthcare: the consultations, diagnostic tests, prescripions, therapies and other interventions that make.

demand for treatments pays attention to the diagnostic and prescriptive processes that interpret the symptoms as presented by a person, and as augmented by further diagnostic test, and supported by available prior information in the person's past.

access to treatments addresses the processes and behaviours with which providers establish order among the requests for care that are randomly received. This theme includes how urgnecy of requests are managed, and as a corollary, how waiting lists are created and managed.

18 Linked Codes:

← **property** — • **capacity**

Linked Codes:
— property → • Provision Network: providers delivering treatments

← **property** — • **coordination level**

Linked Codes:
— property → • Provision Network: providers delivering treatments

← **theme of** — • **Delivers treatment**

Linked Codes:
— theme of → • Provision Network: providers delivering treatments

← **theme of** — • **Diagnoses patient needs**

Linked Codes:
— theme of → • Provision Network: providers delivering treatments

← **property** — • **efficiency - allocative**

Linked Codes:
— property → • Provision Network: providers delivering treatments

← property — • efficiency - technical

Linked Codes:
— property → • Provision Network: providers delivering treatments

— theme of → • Healthcare system

Linked Codes:
← theme of — • Change Theme: how things change
← theme of — • Life Course: healthy lives interrupted by illnesses
← theme of — • Payments Exchange: actors agree to pay for treatments
← theme of — • Provision Network: providers delivering treatments

← flows to — • Information

Linked Codes:
— flows → • Life Course: healthy lives interrupted by illnesses
— flows to → • Payments Exchange: actors agree to pay for treatments
— flows to → • Provision Network: providers delivering treatments

— flows → • Information: accountability

Linked Codes:
— flows to → • Payments Exchange: actors agree to pay for treatments
← flows — • Provision Network: providers delivering treatments

← property — • level of decentralization

Linked Codes:
— property → • Provision Network: providers delivering treatments

← assoc — • Patient

Linked Codes:
— assoc → • Life Course: healthy lives interrupted by illnesses
— assoc → • Provision Network: providers delivering treatments

← flows to — • Payment

Linked Codes:
← flows — • Life Course: healthy lives interrupted by illnesses
← flows — • Payments Exchange: actors agree to pay for treatments
— flows to → • Provision Network: providers delivering treatments

← theme of — • Produces treatment

Linked Codes:
— theme of → • Provision Network: providers delivering treatments

← assoc — • Provider network

Linked Codes:
— assoc → • Provision Network: providers delivering treatments

← flows to — • Request/ referral

Linked Codes:
— flows → • Life Course: healthy lives interrupted by illnesses
— flows to → • Provision Network: providers delivering treatments

— flows → ● Treatment

Linked Codes:
— flows → ● Life Course: healthy lives interrupted by illnesses
← flows — ● Provision Network: providers delivering treatments

← theme of — ● Triages patient requests

Linked Codes:
— theme of → ● Provision Network: providers delivering treatments

← property — ● waiting time

Linked Codes:
— property → ● Provision Network: providers delivering treatments

Appendix C

Model SysML specification

Healthcare System Specification

Package in package 'Healthcare Systems model'

Healthcare System Specification
Version 1.0 Phase 1.0 Proposed
Neil created on 05-May-17. Last modified 05-May-17

Packages diagram

Package diagram in package 'Healthcare System Specification'

Packages
Version 1.0
Neil created on 23-May-17. Last modified 29-May-17

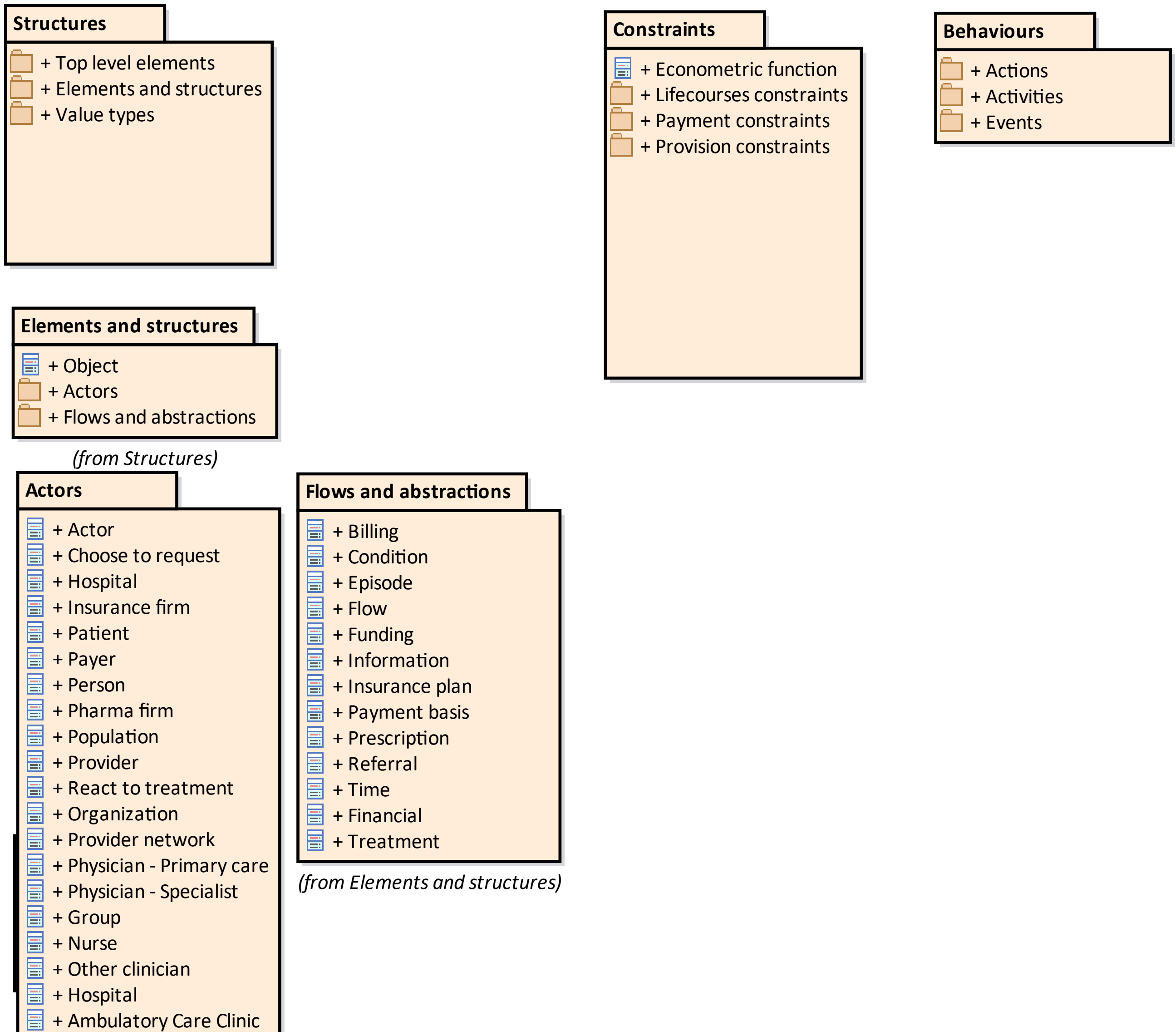


Figure 1: Packages

Structures

Package in package 'Healthcare System Specification'

Structures
Version 1.0 Phase 1.0 Proposed
Neil created on 05-May-17. Last modified 02-Jun-17

Behaviours

Package in package 'Healthcare System Specification'

Behaviours
Version 1.0 Phase 1.0 Proposed
Neil created on 06-May-17. Last modified 01-Jun-17

Constraints

Package in package 'Healthcare System Specification'

Constraints
Version 1.0 Phase 1.0 Proposed
Neil created on 09-May-17. Last modified 21-Jul-17

Actors

Package in package 'Elements and structures'

Actors
Version 1.0 Phase 1.0 Proposed
Neil created on 05-May-17. Last modified 05-May-17

Flows and abstractions

Package in package 'Elements and structures'

Flows and abstractions
Version 1.0 Phase 1.0 Proposed
Neil created on 05-May-17. Last modified 29-May-17

Elements and structures

Package in package 'Structures'

Elements and structures
Version 1.0 Phase 1.0 Proposed
Neil created on 05-May-17. Last modified 29-May-17

Value types

Package in package 'Structures'

Value types
Version 1.0 Phase 1.0 Proposed
Neil created on 30-Jan-16. Last modified 29-May-17

Structures

Package in package 'Healthcare System Specification'

Structures
Version 1.0 Phase 1.0 Proposed
Neil created on 05-May-17. Last modified 02-Jun-17

Top level elements

Package in package 'Structures'

Top level elements
Version 1.0 Phase 1.0 Proposed
Neil created on 29-May-17. Last modified 29-May-17

Constraints and flows diagram

SysML Block Definition diagram in package 'Top level elements'

Constraints and flows
Version 1.0
Neil created on 30-Jun-17. Last modified 30-Jun-17

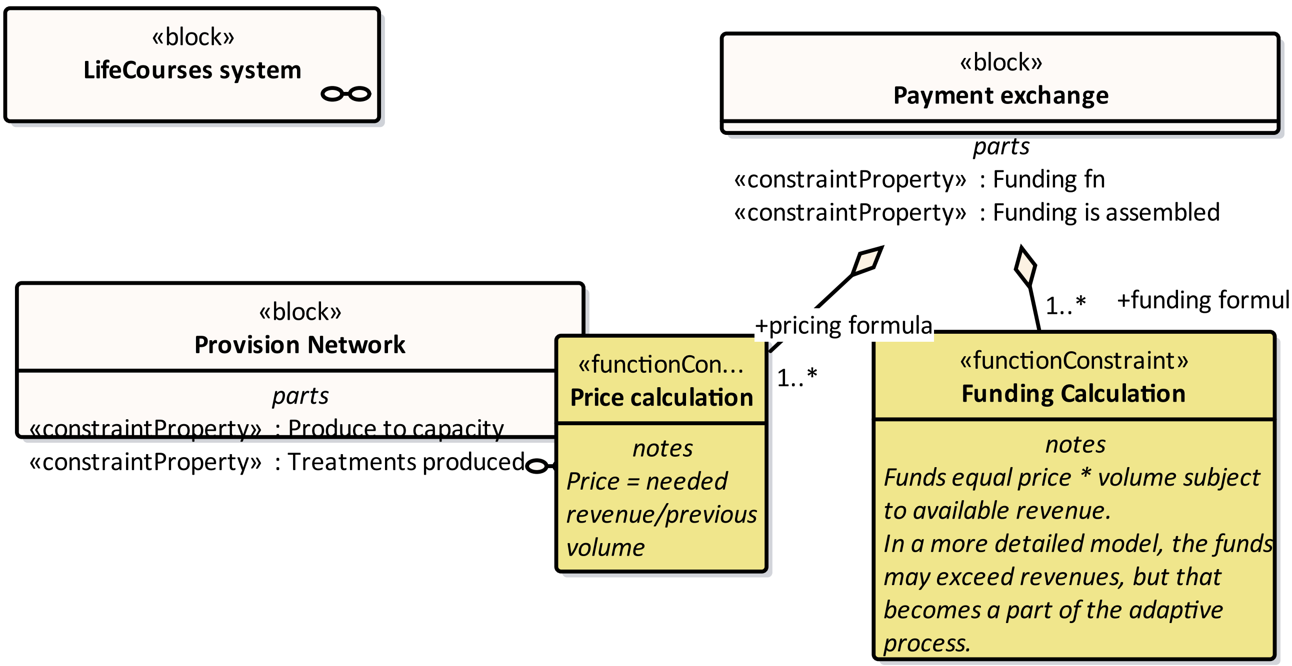


Figure 2: Constraints and flows

Flows among actors diagram

SysML Block Definition diagram in package 'Top level elements'

Flows among actors
Version 1.0
Neil created on 21-Jul-17. Last modified 22-Jul-17

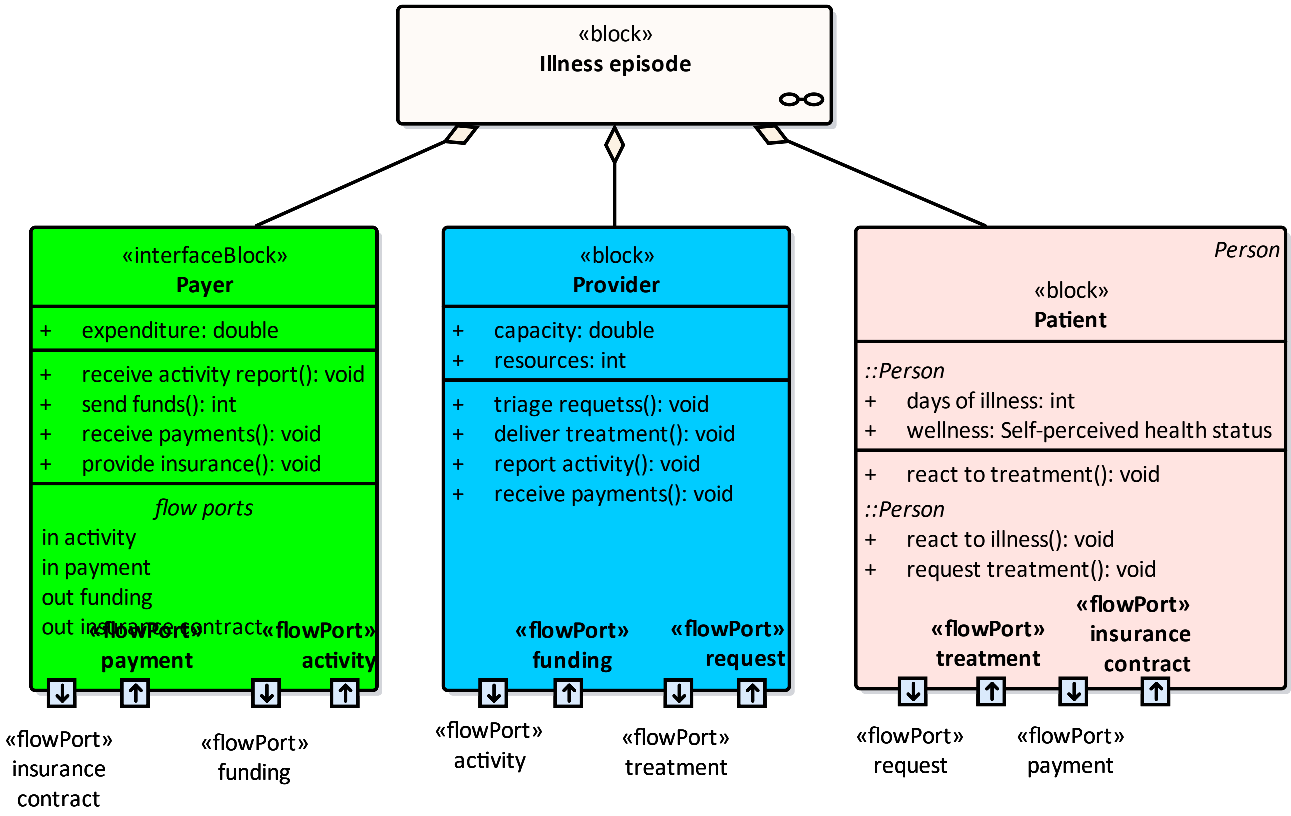


Figure 3: Flows among actors

Patient

Block «block» in package 'Actors'

Patient
Version 1.0 Phase 1.0 Proposed
Neil created on 05-May-17. Last modified 05-May-17
Extends Person

STRUCTURAL PART OF Patient
ConstraintProperty : ConstraintProperty «constraintProperty»
ConstraintProperty : ConstraintProperty «constraintProperty»
trajectory : ConstraintProperty «constraintProperty»
insurance contract : FlowPort «flowPort»
payment : FlowPort «FlowPort»
request : FlowPort «flowPort»
treatment : FlowPort «flowPort»

OUTGOING STRUCTURAL RELATIONSHIPS
Aggregation from «block» Patient to «block» Illness episode [Direction is 'Source -> Destination'.]

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from «block» Patient to «block» Person [Direction is 'Source -> Destination'.]

INCOMING STRUCTURAL RELATIONSHIPS
Aggregation from «constraintBlock» React to treatment to «block» Patient [Direction is 'Source -> Destination'.]
Aggregation from «constraintBlock» Choose to request to «block» Patient [Direction is 'Source -> Destination'.]
Aggregation from «constraintBlock» React to illness to «block» Patient [Direction is 'Source -> Destination'.]

CONNECTORS
Satisfy «satisfy» Source -> Destination From: Payment exchange theme : Activity, Public To: Patient : Block, Public
Satisfy «satisfy» Source -> Destination From: Waiting time effect : Activity, Public To: Patient : Block, Public
Satisfy «satisfy» Source -> Destination From: Treatments and timing modify patient's condition : Activity, Public To: Patient : Block, Public

ATTRIBUTES
care status : CareStatus Protected [Is static False. Containment is Not Specified.]

OPERATIONS
react to treatment () : void Public [Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

ConstraintProperty

ConstraintProperty «constraintProperty» owned by 'Patient', in package 'Actors'

ConstraintProperty
Version 1.0 Phase 1.0 Proposed
Neil created on 22-Jul-17. Last modified 22-Jul-17

ConstraintProperty

ConstraintProperty «constraintProperty» owned by 'Patient', in package 'Actors'

ConstraintProperty
Version 1.0 Phase 1.0 Proposed
Neil created on 22-Jul-17. Last modified 22-Jul-17

STRUCTURAL PART OF /Choose to request: Choose to request
Property : Property

Property

Property owned by '/Choose to request: Choose to request', in package 'Actors'

Property
Version 1.0 Phase 1.0 Proposed
Neil created on 22-Jul-17. Last modified 22-Jul-17

trajectory

ConstraintProperty «constraintProperty» owned by 'Patient', in package 'Actors'

trajectory
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

insurance contract

FlowPort «flowPort» owned by 'Patient', in package 'Actors'

insurance contract
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

payment

FlowPort «FlowPort» owned by 'Patient', in package 'Actors'

payment
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

request

FlowPort «flowPort» owned by 'Patient', in package 'Actors'

request
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

treatment

FlowPort «flowPort» owned by 'Patient', in package 'Actors'

treatment
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

Payer

Block «InterfaceBlock» in package 'Actors'

In systems terminology, this is an "interface". It allows entities that are otherwise quite different to have functional capabilities in common. Specifically this payer interface specifies that the Person, Insurer and Government blocks share the ability to send Payments to Providers. In that respect the functionality is specified separately and is implemented but not owned by the appropriative block.

Payer
Version 1.0 Phase 1.0 Proposed
Neil created on 25-Sep-16. Last modified 13-Jun-17

STRUCTURAL PART OF Payer

Property : Property

activity : FlowPort «flowPort»

funding : FlowPort «flowPort»

insurance contract : FlowPort «flowPort»

payment : FlowPort «FlowPort»

OUTGOING STRUCTURAL RELATIONSHIPS

Aggregation from «InterfaceBlock» Payer to «block» Healthcare system
[Direction is 'Source -> Destination'.]

Aggregation from «InterfaceBlock» Payer to «block» Illness episode
[Direction is 'Source -> Destination'.]

CONNECTORS

Satisfy «satisfy» Source -> Destination
From: Payer : Block, Public
To: Insurer : Class, Public

Satisfy «satisfy» Source -> Destination
From: Payer : Block, Public
To: Government : Class, Public

Dependency Source -> Destination
From: Person : Block, Public
To: Payer : Block, Public

Dependency Source -> Destination
From: Insurance firm : Block, Public
To: Payer : Block, Public

Satisfy «satisfy» Source -> Destination
From: chooses : Activity, Public
To: Payer : Block, Public

Dependency Source -> Destination
From: Government : Block, Public
To: Payer : Block, Public

ATTRIBUTES

cash position : double Private

ATTRIBUTES
[Is static False. Containment is Not Specified.]
insurance policies : double Private [Is static False. Containment is Not Specified.]
expenditure : double Public [Is static False. Containment is Not Specified.]

ASSOCIATIONS	
Association (direction: Unspecified) funding	
Source: Public (Block) Provider «block»	Target: Public (Block) Payer «InterfaceBlock»

OPERATIONS
receive activity report () : void Public [Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]
send funds () : int Public [Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]
receive payments () : void Public [Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]
provide insurance () : void Public [Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

Property

Property owned by 'Payer', in package 'Actors'

Property
Version 1.0 Phase 1.0 Proposed
Neil created on 25-Sep-16. Last modified 25-Sep-16

activity

FlowPort «flowPort» owned by 'Payer', in package 'Actors'

activity
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 22-Jul-17

funding

FlowPort «flowPort» owned by 'Payer', in package 'Actors'

funding
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

insurance contract

FlowPort «flowPort» owned by 'Payer', in package 'Actors'

insurance contract
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

payment

FlowPort «FlowPort» owned by 'Payer', in package 'Actors'

payment
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

Provider

Block «block» in package 'Actors'

Provider
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jun-17. Last modified 13-Jul-17

STRUCTURAL PART OF Provider
adjust_capacity : ConstraintProperty «constraintProperty»
allocate payments : ConstraintProperty «constraintProperty»
Operating funds : Property
produce treatment : ConstraintProperty «constraintProperty»
activity : FlowPort «flowPort»
billings out : Port
funding : FlowPort «flowPort»
payments in : Port
request : FlowPort «flowPort»
requests in : Port
treatment : FlowPort «flowPort»
treatments out : Port

OUTGOING STRUCTURAL RELATIONSHIPS
Aggregation from «block» Provider to «block» Healthcare system [Direction is 'Source -> Destination'.]

OUTGOING STRUCTURAL RELATIONSHIPS

Aggregation from «block» Provider to «block» Referral
[Direction is 'Source -> Destination'.]

Aggregation from «block» Provider to «block» Provider network
[Direction is 'Source -> Destination'.]

Aggregation from «block» Provider to «block» Illness episode
[Direction is 'Source -> Destination'.]

INCOMING STRUCTURAL RELATIONSHIPS

Generalization from «block» Ambulatory Care Clinic to «block» Provider
[Direction is 'Source -> Destination'.]

Generalization from «block» Long-Term Care Home to «block» Provider
[Direction is 'Source -> Destination'.]

Generalization from «block» Other clinician to «block» Provider
[Direction is 'Source -> Destination'.]

Generalization from «block» Physician - Primary care to «block» Provider
[Direction is 'Source -> Destination'.]

Generalization from «block» Physician - Specialist to «block» Provider
[Direction is 'Source -> Destination'.]

Generalization from «block» Hospital to «block» Provider
[Direction is 'Source -> Destination'.]

Aggregation from «functionConstraint» Production function to «block» Provider
[Direction is 'Source -> Destination'.]

Generalization from «block» Nurse to «block» Provider
[Direction is 'Source -> Destination'.]

Aggregation from «functionConstraint» Target revision function to «block» Provider
[Direction is 'Source -> Destination'.]

Aggregation from «ValueType» Currency to «block» Provider
[Direction is 'Source -> Destination'.]

Aggregation from «constraintBlock» Allocation function to «block» Provider
[Direction is 'Source -> Destination'.]

Generalization from «block» Pharma firm to «block» Provider
[Direction is 'Source -> Destination'.]

CONNECTORS

Satisfy «satisfy» Source -> Destination
From: Waiting time effect : Activity, Public
To: Provider : Block, Public

CONNECTORS

Satisfy «satisfy» Source -> Destination
From: Payment exchange theme : Activity, Public
To: Provider : Block, Public

ATTRIBUTES

capacity : double Public
[Is static False. Containment is Not Specified.]

resources : int Public
[Is static False. Containment is Not Specified.]

service type : Service_type Protected
[Is static False. Containment is Not Specified.]

ASSOCIATIONS

Association (direction: Source -> Destination)

Source: Public (Block) Provider «block» Target: Public (Block) Payment exchange «block»

Association (direction: Unspecified) funding

Source: Public (Block) Provider «block» Target: Public (Block) Payer «InterfaceBlock»

OPERATIONS

triage requetss () : void Public
[Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

diagnose disease () : void Protected
[Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

produce treatment () : void Protected
[Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

deliver treatment () : void Public
[Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

report activity () : void Public
[Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

receive payments () : void Public
[Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

adjust capacity () : void Protected
[Is static False. Is abstract False. Is return array False. Is query False. Is synchronized False.]

adjust_capacity

ConstraintProperty «constraintProperty» owned by 'Provider', in package 'Actors'

adjust_capacity
Version 1.0 Phase 1.0 Proposed

Neil created on 13-Jul-17. Last modified 13-Jul-17

allocate payments

ConstraintProperty «constraintProperty» owned by 'Provider', in package 'Actors'

allocate payments
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

Operating funds

Property owned by 'Provider', in package 'Actors'

Operating funds
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

produce treatment

ConstraintProperty «constraintProperty» owned by 'Provider', in package 'Actors'

produce treatment
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

STRUCTURAL PART OF produce treatment / Production function: Production function
fctr : Property
n : Property
pmt : Property
tx : Property

fctr

Property owned by 'produce treatment / Production function: Production function', in package 'Actors'

fctr
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

n

Property owned by 'produce treatment / Production function: Production function', in package 'Actors'

n
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

pmt

Property owned by 'produce treatment / Production function: Production function', in package 'Actors'

pmt
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

tx

Property owned by 'produce treatment / Production function: Production function', in package 'Actors'

tx
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

activity

FlowPort «flowPort» owned by 'Provider', in package 'Actors'

activity
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 21-Jul-17

billings out

Port owned by 'Provider', in package 'Actors'

billings out
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

funding

FlowPort «flowPort» owned by 'Provider', in package 'Actors'

funding
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 22-Jul-17

payments in

Port owned by 'Provider', in package 'Actors'

payments in
Version 1.0 Phase 1.0 Proposed
Neil created on 13-Jul-17. Last modified 13-Jul-17

request

FlowPort «flowPort» owned by 'Provider', in package 'Actors'

request
Version 1.0 Phase 1.0 Proposed
Neil created on 21-Jul-17. Last modified 22-Jul-17

requests in

Port owned by 'Provider', in package 'Actors'

requests in

Appendix D

Multimodel simulation

Model: SMoH8_5

null	null
General	
Model time units	years
Numerical methods	
Differention Equations Method	Euler
Algebraic Equations Method	Modified Newton
Mixed Equations Method	RK45+Newton
Absolute accuracy	1.0E-5
Time accuracy	1.0E-5
Relative accuracy	1.0E-5
Fixed time step	0.001
Advanced	
Java package name	smoh_3
File Name	/Users/MiniMc/Models/AnyLogic local/SMoH8_5/SMoH8_5.alp

Agent Type: Main

nullAt this level, the three systems send treatments, information and payment as messages.

Constants:
People voluntarily purchase insurance if they are in lower ses, have a higher probability of illness, or are required to do so.
Only one illness with slow recovery/fast recovery
People request care if they have coverage

The configuration for each scenario
Scenario 1: growth only, FFS, partial coverage
Scenario 2: as above plus capped budgets
Scenario 3: as above plus universal insurance plus competition

The results for each scenario (time plots)
Census
Expenditure
Access
Waiting

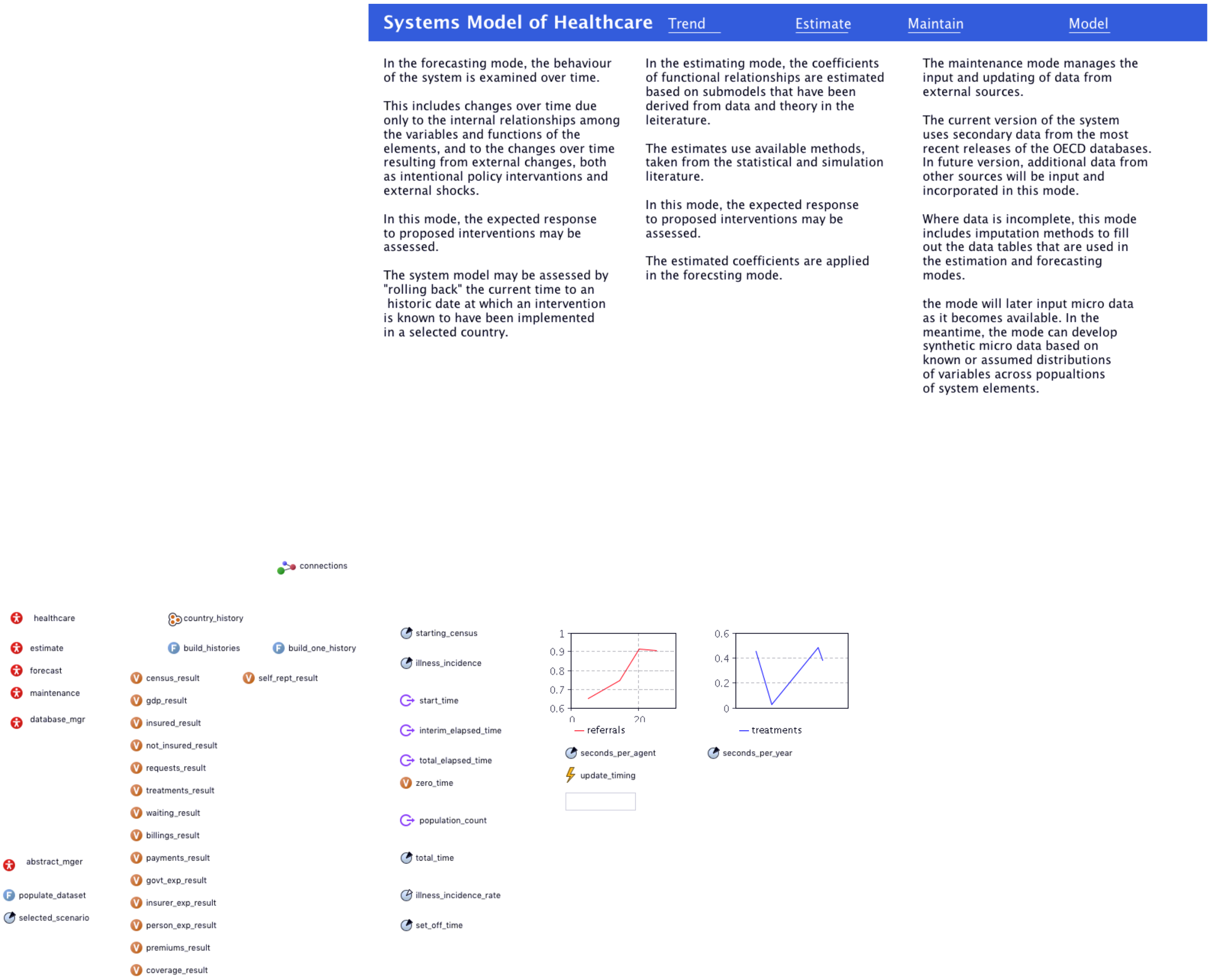
Capped budget means limit on payments which limits capacity and produces waiting lists

Universal coverage means all people have coverage and increases the demand and the contributions to insurance pool.

Competition reduces prices to insurers by reducing costs of provider.

null	null
Agent actions	
Startup code	build_one_history(billings_result);
Agent in flowcharts	
Use in flowcharts as	Agent
Movement	
Speed	(10 : MPS)
Rotate animation towards movement	true
Rotate vertically as well (along Z-axis)	false
Space and network	
Space Type	Continuous

null	null
Dynamic: Width	500
Dynamic: Height	500
Dynamic: z Height	0
Layout Type	User-defined
Layout Type Apply On Startup	true
Network type	User-defined
Network Type Apply On Startup	true
Enable steps	false
Advanced Java	
Generic	false
Advanced	
Make Default View Area	true
Force to be animated by space	false
Flowchart block within a library	false
Logging	true
Auto-create datasets	true
AOC_DATASETS_UPDATE_TIME_PROPERTIES	- Recurring Event Properties
Limit the number of data samples	false
Description	
Description	At this level, the three systems send treatments, information and payment as messages. Constants: People voluntarily purchase insurance if they are in lower ses, have a higher probability of illness, or are required to do so. Only one illness with slow recovery/fast recovery People request care if they have coverage The configuration for each scenario Scenario 1: growth only, FFS, partial coverage Scenario 2: as above plus capped budgets Scenario 3: as above plus universal insurance plus competition The results for each scenario (time plots) Census Expenditure Access Waiting Capped budget means limit on payments which limits capacity and produces waiting lists Universal coverage means all people have coverage and increases the demand and the contributions to insurance pool. Competition reduces prices to insurers by reducing costs of provider.



Scale: scale

null	null
General	
Unit	meter
Scale	10.0
Type	Defined graphically
Length, pixels	100.0
Show at runtime	false
Lock	false
Public	false
Position and size	
x	-160.0

null	null
y	-150.0
Rotation	0.0

Parameter: illness_incidence

null	null
General	
Array	false
Default value	10
Type	double
Show at runtime	true
Show name	true
Value editor	
Editor control	Text
Advanced	
System dynamics units	false
Save in snapshot	true

Parameter: starting_census

null	null
General	
Array	false
Default value	1000
Type	int
Show at runtime	true
Show name	true
Value editor	
Editor control	Text
Advanced	
System dynamics units	false
Save in snapshot	true

Parameter: selected_scenario

null	null
General	
Array	false
Type	int
Show at runtime	true
Show name	true
Value editor	
Label	Show history?
Editor control	Text
Advanced	
System dynamics units	false

null	null
Save in snapshot	true

null	null
Simulated values	false
History	true

Parameter: seconds_per_agent

null	null
General	
Array	false
Type	double
Show at runtime	true
Show name	true
Value editor	
Editor control	Text
Advanced	
System dynamics units	false
Save in snapshot	true

Parameter: seconds_per_year

null	null
General	
Array	false
Type	double
Show at runtime	true
Show name	true
Value editor	
Editor control	Text
Advanced	
System dynamics units	false
Save in snapshot	true

Parameter: total_time

null	null
General	
Array	false
Default value	(System.currentTimeMillis() - zero_time) / 1000
Type	double
Show at runtime	true
Show name	true
Value editor	
Editor control	Text

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