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CAN DIAGRAMS HELP IMPROVE HEALTHCARE SYSTEMS DESIGN AND CARE DELIVERY?

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1. Introduction

"Systems that work do not just happen - they have to be planned, designed and built" [Elliot and Deasley 2007].

In healthcare, the ultimate goal of every system is rather simple - better health for all [WHO 2008]. However, consistently translating this goal into actual experience for patients continues to be a challenge in most countries. In the English National Health Service (NHS), tremendous progress has been made over the past 68 years of its existence but there remain significant challenges to providing care that is consistently safe and of acceptable quality. Munkombwe, in a review, reports that Adverse Events (AEs) have been linked to direct medical costs and lead to an average of 6 to 8.5 extra days of stay in hospital which translate into additional cost of about £2 billion a year for the NHS. Hospital Associated Infections (HAI) occuring to surgery patients alone have also been estimated to cost the NHS £363 million annually, not to mention the harm and loss to patients and their families. [Munkombwe 2010]. More recently, the discovery of systematic failures in some parts of the system [Francis 2013], [Department of Health 2014] has raised serious concerns for all stakeholders. These challenges, however, are not unique to the NHS.

Similar challenges are known to face the health system in the United States of America as well. At the turn of the millennium, it was revealed that the healthcare provided to the poeople of America, in significant number of cases, was not only unsafe but also of deplorable quality. Between the care that patients received and what was considered possible based on available knowledge and technology was not just a gap but a chasm. It was revealed that about 98,000 Americans died annually as a result of avoidable errors in the health system. These were enough to make quality and patient safety part of the major goals of the health system [Kohn et al. 2000], [Institute of Medicine (U.S.A) 2001].

These realities, combined with a continuously growing demand for healthcare and an equally growing need to reduce the cost of healthcare is leading health providers, funders, and other stakeholders to look for solutions from outside healthcare. The fundamental question seems to be, "how do we design better care delivery systems"? It is generally argued that what healthcare needs is the application of tools and techniques that work in engineering and industry [Gorunescu et al. 2002], [Young et al. 2004], [Jahangirian et al. 2010]. These, undoubtedly, have yielded significant results in cost savings and care improvements.

The use of various industry tools and techniques in healthcare is not new. Techniques such as queueing theory [Fomundam and Herrmann 2007], simulation modelling [Jahangirian et al. 2010], [Bensley 2012], statistical process control [Tsacle and Aly 1996], and many more have been applied to various parts of healthcare for several decades. What remains lacking in the healthcare literature is the exploration of a holistic systems design approach to healthcare and what it will take for this to result in systems that work.

We review the relevant academic health service design and delivery literature and make three important observations likely to contribute to the current challenges to designing systems that work in healthcare:

- An increasing diversity of systems modelling techniques aimed at improving healthcare delivery,
- A significant lack of a holistic systems design approach and
- The absence of a consistent diagramming language that can facilitate that improvement.

In this paper we argue that the application of systems engineering to healthcare must invovle an emphasis on systems design and requires a diagrammatic language that engenders shared understanding, communication and problem solving amonst stakeholders.
In presenting this work to the design community, it is especially hoped that this question of the role of design in improving healthcare, will stimulate discussion amongst design researchers and practitioners in order to draw insights that will inform further research.

2. Background

The delivery of high quality patient-centred care continues to be a challenge even in developed countries [Commonwealth Fund 2013], [Care Quality Commission 2014], [Agency for Health Research and Quality 2015]. Evidence from the literature suggests a growing intereest in Systems Engineering for addressing the challenges facing healthcare delivery. In the USA, the publication of two key reports by the Institute of Medicine (IOM) – To err is human [Kohn et al. 2000] and Crossing the Quality Chasm [Institute of Medicine (U.S.A) 2001] – demonstrated the deteriorating state of patient safety and the glaring divergence between the care that was possible and the care that patients were receiving in 2000 and 2001 respectively. The revelation, amongst others, that more than 98,000 Americans died annually as a result of avoidable failures in the healthcare system were enough to place quality of health care firmly at centre stage since 2000. Several reports, initiatives and models have been produced since then but the most relevant to this study is "Building a Better Delivery System" [Reid et al. 2005] published in 2005 and was a culmination of a joint NAE/IOM study. This report launched the "New Engineering/Health Care Partnership". Valdez et al. [2010] identified thirteen major reports that echoed the essence of this new partnership by 2010 and found that the report also heightened the interest of many in solving problems in health care delivery using industrial and systems engineering tools. In a more recent effort, the President's Council of Advisors on Science and Technology (PCAST) was even more optimistic than ten years ago in recommending systems engineering as the way to a better health care system in the USA [Cassel CK and Saunders RS 2014]. In this report to the President, the advisors outlined a set of actions, with selected examples, that government needs to take to speed up progress in the use of systems engineering in health care. It seems therefore apparent that in America, there is a growing sense that systems engineering is what is needed to address the challenges of the health care system. Similar arguments and partnerships exits in the UK though not as strategic [Young et al. 2004], [Jahangirian et al. 2010].
Succeses in industrial systems have always been great attractions to healthcare but "Systems that work do not just happen - they have to be planned, designed and built" [Elliot and Deasley 2007]. This may seem an obvious statement but the non-trivial question that logically ensues is this – how do you design a system that works? The extent to which rigorous design is valued and practiced in an organisation or sector makes a significant difference to quality and performance. Several success stories exist in industry. One example is the transformation of the software industry from what it was in the 1960s to what it is today through the use of an engineering approach (see brief discussion in section 4). It is generally agreed that, that software/engineering partnership is what transformed the industry. It may be too early to predict a similar transformation for the healthcare industry through this new emphasis on systems engineering but we believe it appropriate at this point to critically examine what it will take for this partnership to have the expected impact on patient experience consistently.

3. A brief history of diagramming in industry

The ad hoc use of diagrams and drawings is an inherent part of the thinking and communication processes of every scientific discipline. In mathematics and physics, for example, diagrams play

important conceptual roles, whilst in engineering and architecture, diagrams and formal drawings play a central role in communicating how both conceptual and real-life systems function.
The first known record of the use of diagrams in analysing the productivity and efficiency of processes was by Gilbreth and Gilbreth in 1921 [Patrishkoff 2013]. Gilbreth and Gilbreth presented the use of flow charts as the "first steps in finding the one best way to do work" at the 1921 annual meeting of the American Society for Mechanical Engineers (ASME). In that paper, they argued that "every detail of a process is more or less affected by every other detail; therefore the entire process must be presented in such form that it can be visualized all at once before any changes are made in any of its subdivisions" [Gilbreth and Gilbreth 1921]. The authors presented in detail, the symbols and the standardization required to make the use of flow charts effective in analysing work processes in any field. The work was based on several years of observation and working with numerous organisations.
Since then, the use of several variants of flow charts may be found in several fields including healthcare but often without the rigor with which it was first intended. It is currently difficult to identify one specific field or industry sector that is solely responsible for the development and the effective use of diagrams, however, it may be found from the literature that the fields of software and systems engineering have, by far, attained the most disciplined and systematic use of diagrams as applied to processes for designing complex software and systems. Such systematic approach and disciplined use of diagrams is what this research aims to understand in relation to healthcare systems.

4. Diagrams in software and systems engineering

The first use of the term ‘software engineering’ in 1968 by F.L. Bauer was quoted by Ludewig [1996]: "The whole trouble comes from the fact that there is so much tinkering with software. It is not made in a clean fabricated process, which it should be. What we need, is software engineering." That was the time of what is often referred to as the "Software Crisis"[Naur and Randell 1969]. Software projects of this era were known to be full of error, often hugely over budget, overrun on due date with backlogs of waiting applications [Demarco 1995]. A situation akin to the current challenges facing healthcare delivery in the NHS. F.L. Bauer became the chair of the first conference on Software Engineering in 1968, funded by the NATO Science Committee [Naur and Randell 1969].
This led to significant work, by both researchers and software developers, resulting in several methods and diagramming languages for structuring, organising, designing and engineering software in the 1970s and 1980s [Endres 1996]. By the early 1990s, most of these languages appeared to be converging in terms of their objectives and semantics. As a result, in 1995 the Software Industry undertook to integrate the existing languages into one language – The Unified Modelling Language (UML) [del Aguila et al. 2014]. UML is currently the industry standard in terms of diagrammatic modelling for software systems and parts of it have also been used in other fields including healthcare.
One of the earliest Software Engineering tools, Structured Analysis Design Technique (SADT)[Ross 1977], developed in the 1970s was adopted and extended into a series of diagramming languages - Integrated Definition (IDEF) - employed by the US Air Force [Knowledge Based Systems, Inc. 2010]. Like the software industry, the US Air Force adopted the SADT tool in order to help address "the need for better analysis and communication techniques for people involved in improving manufacturing productivity" [NIST 1993]. The IDEF series (IDEF0, IDEF1, IDEF1x …) became the modelling language for diagramming in Systems Engineering and is still in use, but with the development of UML, the Systems Modelling Language (SysML) has also emerged as the industry standard in the field of Systems Engineering. SysML mainly reuses many of the diagramming types in UML, modifies some of them and introduces a few new ones [Object Management Group 2011].
Two things are noticeable after reviewing this background. The first is that most of the tools developed in software and systems engineering were developed for use by people with expertise that are not usually found in those who design and manage healthcare systems. Hence our preliminary and anecdotal analysis of the current practice of diagramming in healthcare shows that several of these industry driven tools have found their way into healthcare and are employed in an unstructured manner. Secondly, it seems that these developments were more driven by industry than by academia. This means that people who already understood how software development works undertook the task of developing new ‘tools

for the trade'. Hence we argue that it is important that in applying diagramming methods to healthcare, modellers and analysts must seek to develop a good understanding of how healthcare works as a system.

5. Diagrammatic representation and reasoning

Diagrammatic models or representations of all forms are primarily tools for reasoning and communication mainly between humans but sometimes machines. For this reason a huge body of work exists that has, for centuries, examined the semiotic elements and cognitive aspects diagrammatic communications and languages. Gurr [1999] identified that, like other systems of communication, diagrammatic communication also involves studies in semantics, syntactics and pragmatics. However, he found that significant amount of the literature has focused more on the semantics and syntactics of diagrams and less on the pragmatics. Similarly, Blackwell [2011] noted that the study of diagrammatic reasoning has focused predominantly on computational models of diagram use rather than study of human performance in using diagrams. With these observations, one may begin to understand why the several diagramming methods often taken from engineering into healthcare seem ineffective in supporting good service design. There is a significant lack of consistency in the use of diagrams in healthcare with a prolifiration of different techiniques all of which have their roots in industry. As Tversky [2011] has argued, good design of a diagrammatic language must take into account the information-processing habits and limitations of human users. This is why in this paper, we argue for the need for a healthcare-specific diagrammatic language.

6. The state-of-the-art in Healthcare

We have discussed the systems challenges to healthcare and the value of systems engineering and for that matter diagramming in industry and its potential for healthcare. In this section we focus on presenting a review of the state-of-the-art in the use of diagramming in healthcare from a research perspective. We are excluding an examination of the current practice in order to keep this paper within the limit required for the proceedings. Figure 1 below summarise the mothodology that was followed in identifying the most relevant studies.

A full analysis of the literature is presented in the appendix. The results, however, show that no study that seeks to apply diagrammatic modelling to healthcare approaches the subject from a holistic systems design perspecitve. The important implication of this observation is that though diagrammatic modelling is often applied to healthcare in the context of "systems engineering" most studies do not conceptualise a whole system even emplicitly.

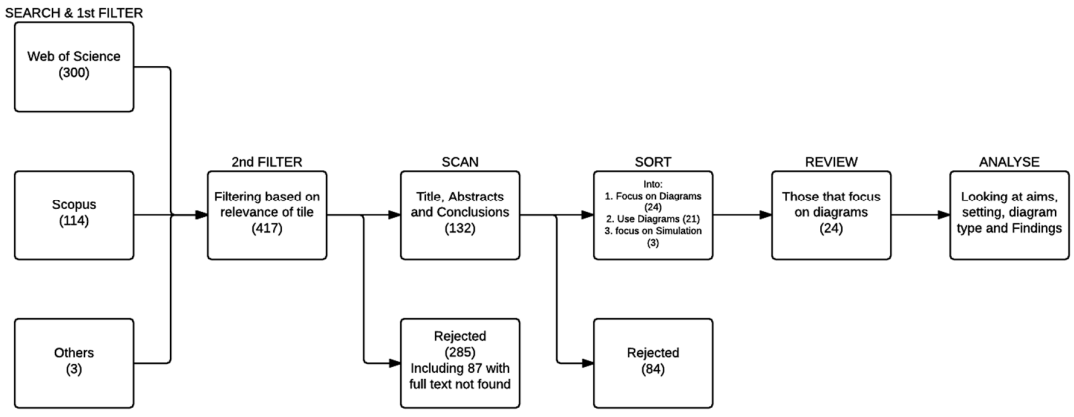

Figure 1. Review methodology

6.1 A prolifiration of diagramming methods

The 23 academic sources reviewed in this paper, addressed 35 different diagrammatic methods including UML Classs diagrams, UML Activity diagrams, Flowcharts and Swimlanes. Of all the methods identified, Flowcharts appeared to be the most used but even that was employed in only 5 studies. UML Activity diagrams appeared in three studies and nine other methods appeared in only two studies. All the remaining methods identified appeared in only one study each. Clearly, there is a wide range of diagramming tools being used in the efforts to improve healthcare delivery but it is evident that they are all tools developed in industry and exported into healthcare. Based on these observatinos we question if this trend of a growing diversity of diagramming tools employed in healthcare is helpful for designing better delivery systems in heathcare. We suggest it is not.

6.2 A lack of holistic systems approach

Further examination of the academic sources reviewed shows that almost all the studies had a primary focus on processes. As we will argue in section 7, a systems view of healthcare must involve much more that the processes. We acknowledge that most studies may be constrained by their objectives and may justify a focus on limited aspects of the system but our argument is that if we are going to make progress in designing better delivery systems, then we need to seek to understand how healthcare works as a system and have the language for describing it.

6.3 Design in healthcare

Unlike the industry sector that employs thousands of design and systems engineers, the vast majority of the people who design healthcare systems and services have little or no formal training in the design or engineering of systems. This is consistent with reports that the NHS is significantly behind in the practice of design [DoH 2003]. It is for this reason that a language for describing healthare sysetms has to be right for healhcare practitioners and stakeholders. A diagrammatic language for healthcare has to be designed to be simple, intuitive, transparent and should facilitate a holistic systems design approach.

7. The case for diagrams in Healthcare

To date, there has been no focused development with respect to the use of diagrams in healthcare, though the use of diagrams is common place. And to our knowledge, no study exists that has focused on the development of a healthcare-specific diagramming method. Nevertheless, it is known that the type of diagrams used to describe elements of a system in healthcare has important implications for the outcome of specific healthcare design projects. In a recent study by Collingan colleagues [Colligan et al. 2010], it was found that the layout and type of process map used in service design influences healthcare practitioners' perception of quality and safety problems in a process. Jun et al. sought to develop a framework to guide healthcare practitioners' decision about when to use different types of the available diagramming tools [Jun et al. 2009]. Within the NHS, years of work has been done on process mapping and analysis involving the use of flow charts, however, there has been no significant focus on the role of the diagramming language and a systematic use of it [NHS Institute 2013].

We propose a conceptual diagrammatic model of healthcare that adopts a holistic view of the system. This is a high level of conceptualisation and will require further development. The goal is to begin to conceptualise healthcare in a way that is relevant at multiple levels and which allows emphasis to be placed on various aspects of the system as required. The proposed model is shown in Figure 2.

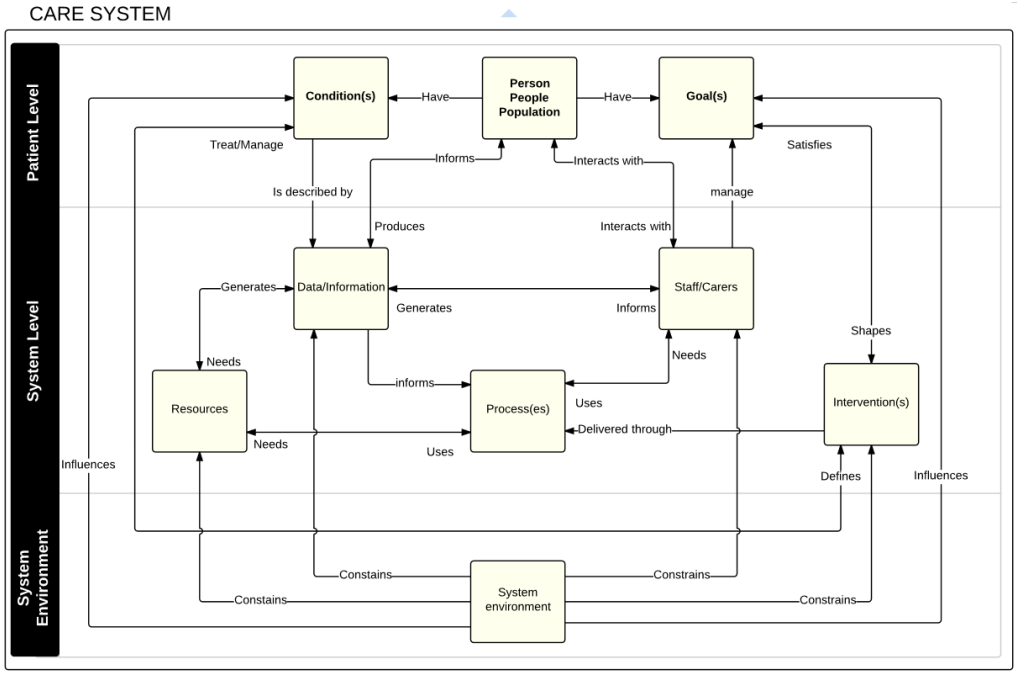

Figure 2. A proposed conceptual diagrammatic model of healthcare

7.1 A holistic systems view of healthcare

In developing Figure 2, we sort to identify the major elements of a healthcare system that can be represented at different levels of abstraction and the relationships between them should be. The nine elements are laid out so as to reflect the logical progression of design decisions to be considered in designing and operating a delivery system in a systematic manner. At the patient level we identify the the person, people or population as central to the system. They may have conditions and also have corresponding goals. Treating or managing the conditions and goals require the sytem level elements - Staff, processes, data/information, interventions and resources. The next level, which is the system environment shows that those elements required to manage the patient's condition and goals can be significantly constrained by several factors within the system's environment.The basic argument is that, it any of these key elements are ignored in the design of the delivery system, it is likely that it will not perform as expected in the long term. It is important to hold this holistic view in any design and not only a focus on one or two aspect as is seen in the literature.

8. Conclusions and future work

This paper has discussed the challenges that face healthcare delivery and the growing interest in systems engineering as the answer. We have presented a summary of the exisiting literature and found a lact of emphasis on whole system perspective and design. We propose:

1. More holistic systems design approach and not just the use of systems tools and techniques in healthcare.
2. A consistent diagrammatic language for communication and description of healthcare systems.

This paper presents significant opportunity for further work in the area of the application of diagrams in healthcare. In the first place a diagrammatic laguage that is empirically developed for the healthcare domain is needed as the tools from industry do not often take into account the pragmatics of diagram usage in healthcare. There is also the opportunity to refine our holistic diagramming framework and formulate approaches to developing the detailed descriptions of each of its elements.

It must be born in mind that this work has limitations. The main limitations are that the domain of search for the literature was limited to Web of Science and Scopus. It is therefore possible that any work outside

of this domain may have been missed in this analysis. However, given the broad scope of our two sources, we are confident that very little would have been missed.

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Table 1. Summary of key literature on diagramming in healthcare

References (Country)	Aim	Healthcare area	Diagram type	Findings
[Askari et al., 2013] (Netherlands)	To propose a modelling approach based on Disease Management.	Fall management in elderly people	UML Activity Diagram	Modelling care processes using questions about the condition aids understanding, communicating and assessing the delivery process.
[Lane, 2013] (UK)	Review how technologies have supported the teaching and learning of diagramming.	N/A	No specific type	Lack of published research studies on diagramming as part of systems practice
[Rebuge & Ferreira, 2012] (Portugal)	To develop a methodology based on process mining to support Business Process Analysis in healthcare	Radiology workflow in a hospital emergency service	Business Process Analysis, Process mining, PetriNets	Methodology allows sequence clustering playing a key role in identifying regular behaviour, process variants and infrequent behaviours.
[B. Huang, Zhu, & Wu, 2012] (China)	To propose a methodology to manage lifecycle of healthcare process modelling through customer-specific knowledge	Anemia in pregnancy	Customer-centred careflow process modelling system	System provides efficient way to build process models and offer better reusability of models.
[Goodwin-Wilson, Watkins, & Gardner-Elahi, 2010] (UK)	To develop evidence-based process maps for spinal cord injury	Spinal cord injury rehabilitation	Tabular maps	Developed maps can be used to identify need for service change, audit and provide evidence-based expectation for staff.
[Gyuchan T. Jun et al., 2011] (UK)	To develop a framework to help healthcare workers select modelling methods	Health service transformation team	28 different models	The framework assists health professionals to commision more appropriate modelling works.
[Colligan, Anderson, Potts, & Berman, 2010] (UK)	To examine the influence of types of diagrams used on quality of care improvement work.	Community based anticoagulation clinic	Sequential Flow Diagram, Hierarchical Task Analysis Diagrams	The layout of a process map can influence healthcare practitioners' perception of quality and safety problems in a process.
[Vanhaecht, De Witte, Panella, & Sermeus, 2009] (Belgium)	To assess differences in the perception of health professionals in their evaluation of care process.	Belgian-Dutch clinical pathway network survey	None presented	Groups with pathways in place for less than one year had highest scores. Propose a critical period for pathways use is one year after which effective use may decrease.
[Van Vliet et al., 2011] (Belgium)	To compare process designs of three high-volume cataract pathways.	Eye hospitals in UK, USA and Netherlands	Flowcharts Lean framework	Pathways in UK and Netherlands were more effective than those in the USA.
[Gyuchan T. Jun, Ward, Morris, & Clarkson, 2009] (UK)	To evaluate how healthcare workers perceived the usefulness of selected process mapping methods	Discharge process Diabetes process Prostate Cancer	Nine different diagrams	Recommends it is best to use multiple diagram types to deal with complexities in healthcare.
[Garcia Rojo et al., 2008] (Spain)	To report use of business process modelling notation to model a pathology process	Surgical pathology	Business Process Modelling Notation	Models made communication of processes easier and allowed dectection and correction of erros
[Shukla, Keast, & Ceglarek, 2014] (UK)	Present a systematic and semi-automatic methodology for knowledge acquisition with detailed prcess representation	Radiology service	Role Activity Diagrams, Value Stream Mapping, IDEF0	Role Activity Diagrams are a flexible approach that can be modified and edited for inconsistencies.

Table 1 continued

References (Country)	Aim	Healthcare area	Diagram type	Findings
[Staccini, Joubert, Quaranta, & Fieschi, 2005] (France)	Developing a tool that makes it possible to extract data on a given process based on the description of its elements and to locate documetns according to its activities	Transfusion medicine	IDEF0/SADT	Tool allows considering different levels of aggregation needs while reusing already defined components. Models are simple, transparent and understandable.
[Stuit, Wortmann, Szirbik, & Roodenburg, 2011] (Netherlands)	To evaluate a novel interaction-centric process modelling method.	Human Collaboration Processes of a Head and Neck oncology care pathway	Flowchart, Agent Structure Diagram, Interaction Structure Diagram, Web tool	Method is a useful and effective tool to capture and model human interaction structure in the target Human Collaboration Processes.
[Tello-Leal, Chiotti, & David Villarreal, 2012] (Mexico)	To develop software for integrated coordination of processes across organisational boundaries.	A general hospital and a specialist hospital	Business Process, Modelling Notation, PetriNet, Software platform	Proposed tool shows organisations can derive high quality and improve communication in the integration and coordination of services when they focus on cros-organisational processes.
[Shahzad & Zdravkovic, 2012] (Sweden)	To develop an approach to business process analysis using process warehouse.	Stroke process	Goal-driven process analysis	Developed process overcomes lack of methods for guiding analysis and improvement using the data related to running business processes.
[Weber et al., 2011] (Austria)	To develop a method for managing a database of complex process models	Several	Business process models	Introduced a method for aiding process designers to manage large repositories of process models.
[Y.-H. Huang & Gramopadhye, 2014] (USA)	To demonstrate the value of systematic engineering approach to medication administration.	Medication administration	Work system Analysis, Workflow diagram, Hierarchical Task Analysis	Study demonstrates the use of systematic methodology to describe and identify potential issues in a clinical activity. Practitioners should realise that process improvement or workflow redesign is a continuous journey.
[Deneckere et al., 2012] (Belgium)	Study the impact care pathways on interprofessional teamworking.	Cluster Randomised Control Trial in Belgium, Ireland, Italy and Portugal	None presented	Reported proposed work. Hopes results will allow researchers and health managers to draw conclusions on relationship between care pathways and team output.
[Behnam & Badreddin, 2013] (Canada)	Propose a Care Process Metamodel (CPM) to address problem of great number of care pathways and many variations.	Business Intelligence monitoring of care processes	UML Class Diagrams	CPM approach can capture hierarchical decomposition of processes therefore good for modelling complex care processes.
[Siriwardena & Gillam, 2013] (UK)	To explain why it is important to understand healthcare processes in order to improve them.	Influenza vaccination	Flowcharts, Logic models, Fishbone diagram, Driver diagram	None
[Barach & Johnson, 2006] (USA)	Describe process mapping work focusing on how map helps to understand complexity and human factors.	Pediatric cardiovascular surgical care	Flowcharts	Process maps are useful but a way of representing systems at different levels of granularity is needed.
[Reijers et al., 2015] (Netherlands)	To develope a framework for evaluating the quality of business process models.	Generic	Business process models	Introduced the SIQ framework for evaluating the quality of business process models.