INTERNATIONAL DESIGN CONFERENCE - DESIGN 2010
Dubrovnik - Croatia, May 17 - 20, 2010.

DESIGN 2010

THINKING WITH SIMPLE DIAGRAMS IN HEALTHCARE SYSTEMS DESIGN

T. G. Jun, S. Hinrichs, T. Jafri and P. J. Clarkson

Keywords: diagrams, systems design, healthcare, modelling language

1. Introduction

Healthcare systems are continuously redesigned to meet a variety of quality requirements: patient safety, patient experience, efficiency and clinical effectiveness. While there is increasing recognition that developing a good systems understanding is an essential step to effective healthcare systems design [Edwards, 2005], a good systems understanding is often lacking in healthcare [Clarkson et al., 2004].

In a domain like engineering design, there has been a long tradition of using diagrams as part of the design process. Various diagrammatic representations have been extensively applied to understand and communicate complex systems, and solve ill-defined problems [Purcell and Gero, 1998]. More recently, diagramming has been also highlighted as means to graphic elicitation of highly complex or sensitive topics [Crilly et al., 2006].

On the other hand, the usage of diagramming in healthcare has been very limited to flowchart-based care pathway descriptions [Pradhan et al., 2001]. A single diagram type is known to simplify only a certain view of reality [Pidd, 2003]. Jun et al. [Jun et al., 2010] also pointed out that a single diagram cannot effectively capture the full range of perspectives present in complex healthcare delivery, which consists of various stakeholders, information and tasks. The need has been raised for better application of diagrammatic representations to the design of healthcare systems [Clarkson et al., 2004].

Unlike product and engineering design processes which have trained dedicated designers, clinicians and healthcare managers, who continue to provide care services, also play significant roles in designing healthcare systems. Thus, diagrammatic representations, if they were to be used for the design of healthcare systems, need to be usable and useful to clinicians and healthcare managers.

Therefore, this paper aims to investigate how healthcare workers perceive various diagram types in terms of usability and utility. It also examines the roles of different diagram types in various healthcare contexts: medication management process; medical device purchasing process; patient diagnosis process. It concludes with insight into how to use various simple diagram types for healthcare systems design.

2. Various diagram types developed for systems modelling

Since the 1970s, software and systems engineers have developed many types of graphical modelling languages that support the analysis, specification, design, verification and validation of complex systems. These languages, which consist of several different diagram types, include Structured Analysis and Design (SA/SD), Integrated Definitions (IDEF) and Object-Oriented Method (OOM). Collective efforts have been also made to unify diverse modelling methods and led to the development of Unified Modeling Language (UML) for software engineering [Fowler and Scott, 2000] and Systems Modeling Language (SysML) for broader domains including hardware, software, information,

processes, personnel and facilities [Friedenthal et al., 2008]. SysML, for example, includes nine different diagram types as shown in Figure 1.

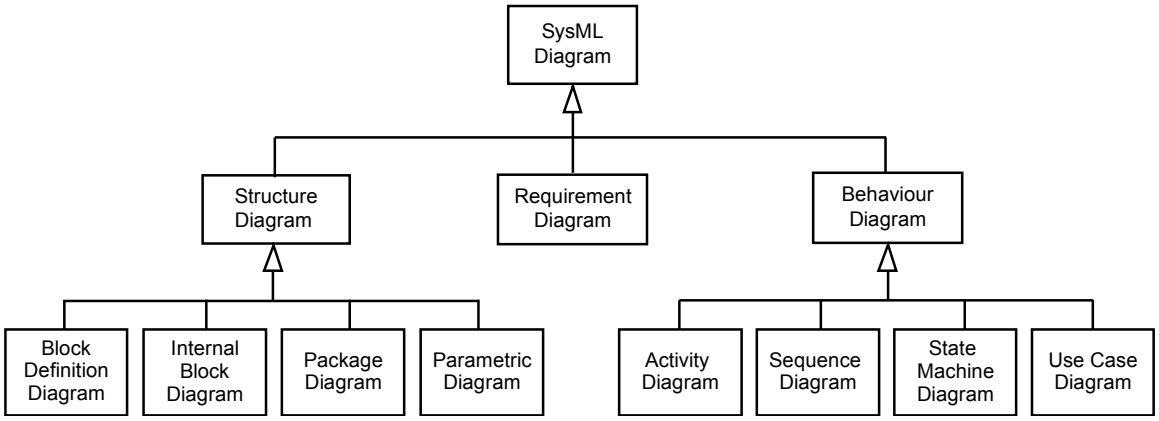

Figure 1. SysML diagram taxonomy [Friedenthal et al., 2008]

In order to apply such a general-purpose modelling language like SysML to a specific domain like healthcare, domain-specific issues, healthcare systems and users need to be taken into account. As an initial attempt to apply a broad range of diagram types to the representation of the healthcare system operation, Jun et al [Jun et al., 2010] identified ten different diagram types with distinct differences. Modelling approaches for simulation purpose only were not included. Figure 2 positions each of the ten diagram types in terms of nodes (boxes and circles) and links (connecting lines between nodes). Jun et al [Jun et al., 2010] also evaluated how healthcare workers perceived the applicability of these diagrams, but in rather limited healthcare contexts (patient journeys through multiple departments). So, this paper applies various diagram types to a broader range of healthcare contexts: medication management process, medical device purchasing process and patient diagnosis process.

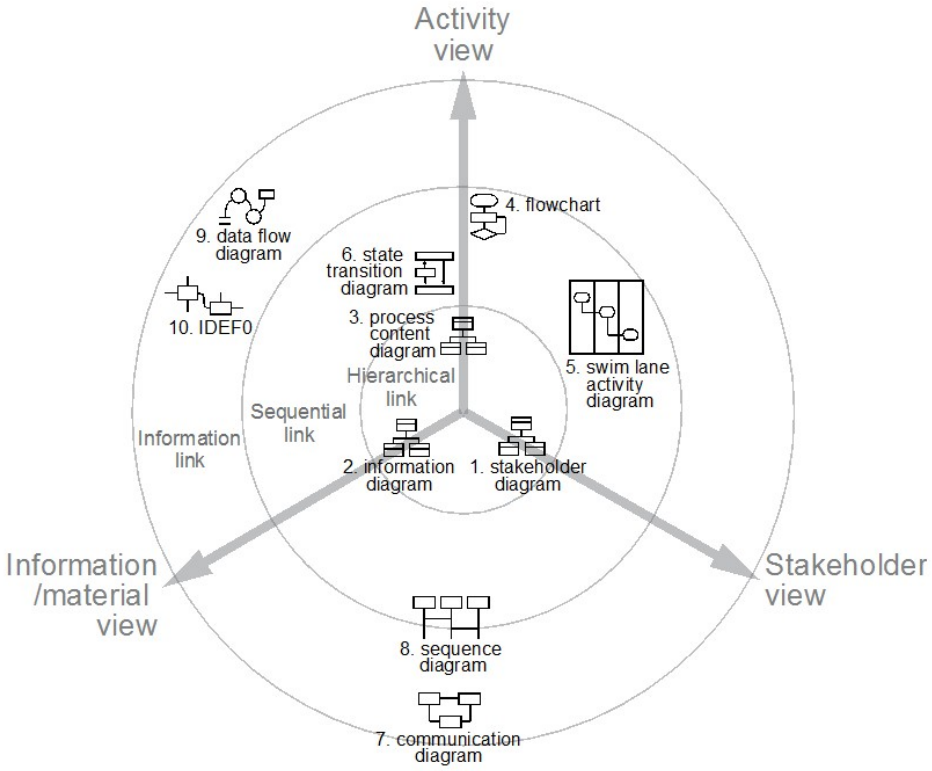

Figure 2. A framework for systems modelling method characterisation [Jun et al., 2010]

3. Methodology

Three case studies were carried out to investigate the use of diagrams in three different healthcare contexts: medication management (case 1), medical device purchasing (case 2) and patient diagnosis (case 3). In each case study, the researchers initially collected systems information (how systems work) through either workshops or semi-structured interviews with healthcare workers. In addition, national and local policy documents were obtained as a source of general systems information. The researchers attempted to generate draft diagrams based on initial systems information and actively used them in the following workshops or interviews to elicit further systems information. Diagrams were populated further through each new interview or workshop and continuously developed into a more comprehensive diagram of the full system.

Diagram types for each case were chosen considering both system aspects that the researcher wanted to represent and the characteristics of the diagram types identified in Figure 1. In the first case (case 1), a communication diagram (information/medicine flows between stakeholders) was used to represent medication management process, which consisted of many medicine and information flows among multiple stakeholders. The second case (case 2) used flowcharts to represent medical device purchasing process which involves multiple decision-making stages for clinical, technical and financial requirements. The third case (case 3) used state-transition diagrams to represent patient's state changes in a diabetes diagnosis process.

Finally, generated diagrams were used with healthcare workers either in group or one-to-one sessions for three main purposes: systems understanding, risk analysis and systems (re)design, but with a different emphasis in each case. The participants' feedback and comments on the use of the diagrams were captured and reported in this paper to show how they perceived the roles of diagramming. Table 1 summarises the details of the three cases.

Table 1. Summary of methodology for three cases

	Case 1	Case 2	Case 3
Processes to be mapped	- Medication management	- Medical device purchasing	- Diabetes patient diagnosis
Systems information gathering methods	- Document analysis - Workshops - Semi-structured interviews	- Workshops - Semi-structured interviews	- Document analysis - Semi-structured interviews
Diagram types used	- Communication diagrams	- Flowcharts	- State-transition diagrams
Engagement methods during diagram usage	- Interviews with 25 stakeholders - Workshop with seven stakeholders	- Interviews with five healthcare workers	- Interview-based questionnaire with six healthcare workers

4. Results

4.1 Case 1 – Medicine management process

In the UK, the NHS is the sole healthcare provider where approximately 2.3 million medicines are prescribed each day [Smith, 2004]. There are three main supply routes for prescribed medicines in the NHS, in addition to the growing and emerging supply of medicines through the home care and internet

pharmacies. However, to date the role of the pharmaceutical supply chain in medication error (or the medicines journey from the manufacturer through to the patient) and the associated risk in this process remains largely unexplored in the published literature.

In this case, the medication management process was explored with stakeholders using a communication diagram, shown in Figure 3. The diagram represents the interactions between collaborating parts from pharmaceutical manufacturer through to the end-user the patient. There were very few comprehensive models or diagrams of parts of the medication management process and therefore asking respondents to help develop and evaluate the diagrams was vital. Stakeholders from the medication process chose this communication diagram as the clearest representation of how medicines were delivered to the patient in comparison to some other diagrams such as state-transition diagrams and hierarchical task analysis diagrams. The diagram was instrumental in motivating systems thinking as shown in the following comment by one participant (patient).
"Gosh that's a long journey for a medicine."

The diagram was then used to think about risk to medication safety and some interviewees commented that risk was at every link and identified that there were a lack of safeguards built into the system.

"Well, the risks are based on the number of links in chain and whether we understand, I hadn't realised that."

"For every drug we dispense, how many administrations are there? So you could have the same administration errors repeated over and over a time from one supply"

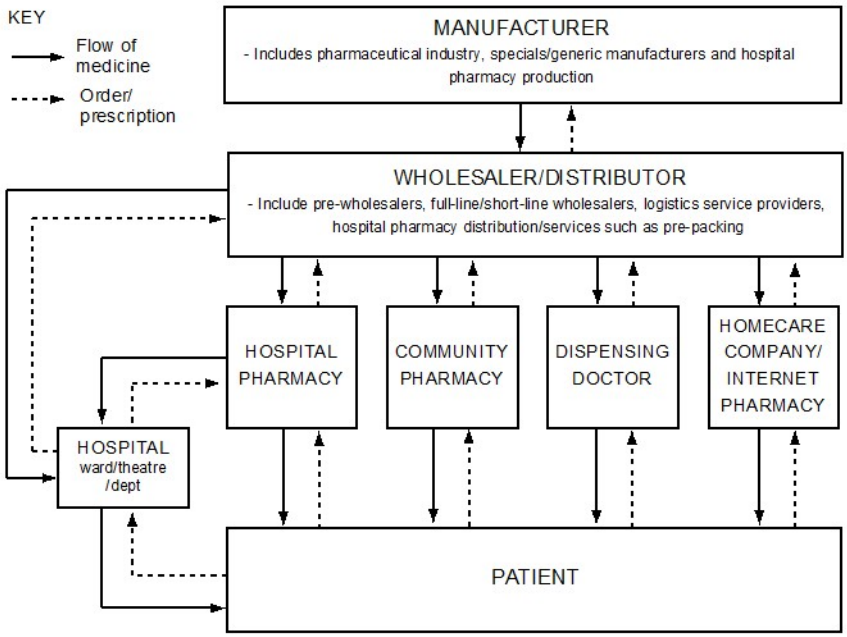

Figure 3. Communication diagram representing medicine and information flows

Furthermore, new threats were identified. Most respondents noted many possible entry points on the communication diagram and felt that more needed to be done to deal with the threat of counterfeit medicines in the bona fide supply chain.
"I would say it can enter the chain at the wholesaler level and also at the pharmacy level mainly, which is worrying because of high levels of parallel imports."
The most difficult or ambiguous interaction was identified between the patient and community/hospital pharmacy.

"We don't do enough to help patients in either hospital or community pharmacy. We don't have the time to tell them how to take their medicines properly."
This case therefore demonstrates the invaluable contribution that diagramming made to healthcare systems analysis and design. Diagramming can be used to engage healthcare stakeholders, elicit their perceptions of risk and encourage systems (re)design.

4.2 Case 2 – Medical device purchasing process

Figure 4 shows the flowchart of the decision-making process occurring for medical device purchases in a large hospital. This basic flowchart is one of the very first skeleton diagrams used with the participating stakeholders for capturing their own processes. It was not intended as a full and comprehensive depiction of the process but as a tool to elicit further discussion. Some arrows and activities were therefore purposely omitted.
This approach was particularly useful in this context, given that the knowledge base and responsibility for the purchase of devices within a hospital lies in different parts of the organisation. Stakeholders from clinical wards, from clinical engineering and maintenance and from the purchasing office are typical contributors to this process in any given hospital. Their training, background, and extent of involvement can vary depending on the particular device being purchased. Figure 3 provided a useful means to collecting the different viewpoints, piecing the puzzle together and providing a holistic view of a system, as commented by one of the participants (senior clinical engineering).
"I think the flowchart gave us the focus to concentrate on the issues in a more holistic sense"
The final diagram produced was presented back to all individually interviewed stakeholders in a workshop setting, in which risks in the process were elicited.

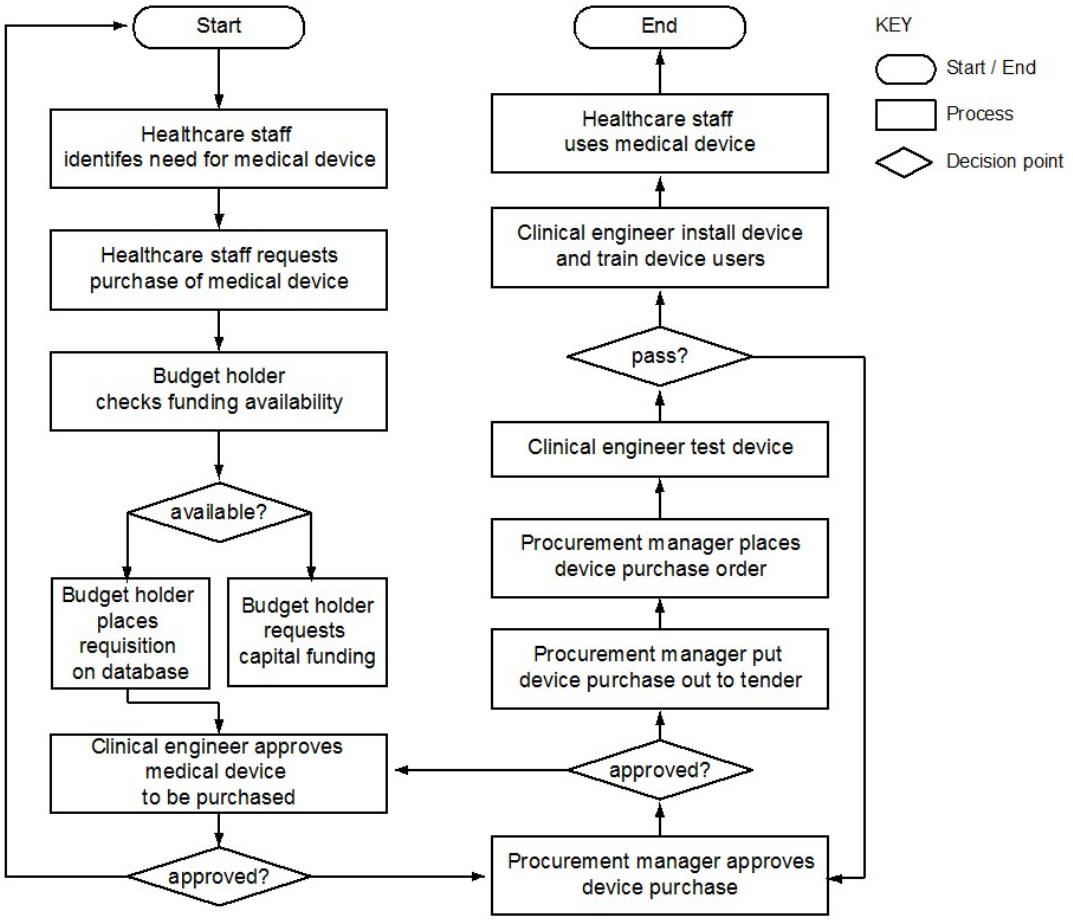

Figure 4. Flowchart representing various decision-making in medical device purchase process

4.3 Case 3 – Diabetes patient diagnosis process

Figure 5 shows a state-transition diagram describing the diabetes patient diagnosis process. This diagram was chosen for this case since it proved very unique to describing care processes from patient's perspective compared with the other diagram types in Figure 2 [Jun et al., 2010]. It was used on a one-to-one basis to help healthcare workers understand how the system works and analyse risk in it.

State-transition diagrams have been used to define the way in which a system's behaviour changes over time, but have not been much used in describing patient care processes. To apply this diagram type to care processes, system's states in this study were defined as patient-related states such as the patient's physical status, the patient's location and the status of the patient's information.

The following comments from the participating healthcare workers shows that state-transition diagrams are perceived, although initially unfamiliar to most of them, easy to understand and useful particularly in describing care processes from patient perspectives. In addition, state-transition diagrams were perceived to be a very efficient way to describe complex and long care processes in a compact manner.

"I quite like that. It tells you everything and each state, and (is) quite user-friendly"

"I think this (state-transition diagrams) is better than flowcharts. It is patient-led and shows clearly what stage a patient is at."

"I quite like the fact that it (state-transition diagram) follows patients, and what happens to the patients. You can have different states of patients and also you can have quite in-depth information underneath what is happening."

When asked about the utility of the diagram for risk analysis, many respondents said that the diagram was helpful in identifying hazards – i.e. going through all the elements of the system without missing out any – but less helpful in estimating consequences of hazards. But the potential utility of the state-transition diagrams for risk analysis was also mentioned.

"Hazards are identifiable through the diagram, but hard to estimate the consequence of those hazards."

"The state in state-transition diagram could be the states of patient harm. Patients have to stay in the previous state, if any task fails."

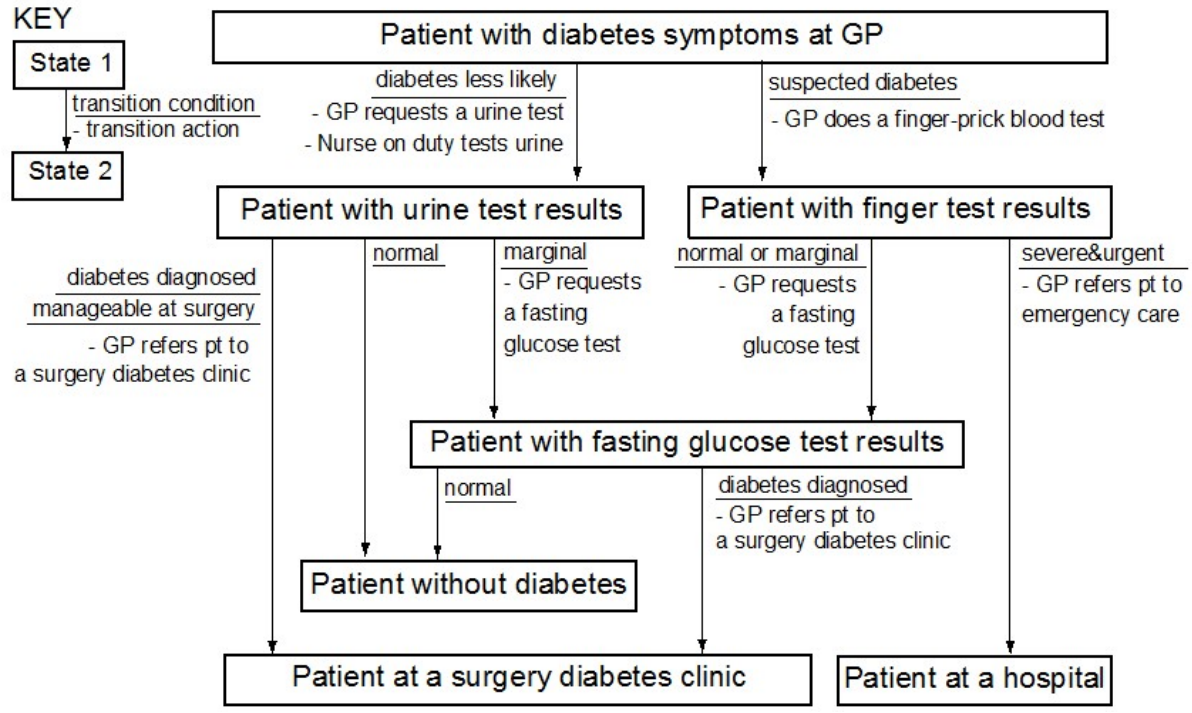

Figure 5. State-transition diagram representing diabetes diagnosis processes

5. Conclusion and further research

Commonly throughout the three cases, the diagrammatic representations helped healthcare workers improve systems safety by providing a holistic picture of the system, often called a helicopter view, for thorough risk analysis. Table 2 summarises the roles of the diagrams in each case.

Table 2. Roles of the diagrams in each case

	Case 1	Case 2	Case 3
Roles of the diagrams	- Motivating systems thinking - Engaging healthcare stakeholders - Identifying hazards to medication safety	- Providing a holistic systems understanding - Collecting different view points - Identify hazards in the purchasing process	- Providing patient-centred systems understanding - Identifying hazards, but less instrumental in analysing risks

The researchers found that not only the diagrams themselves, but also the engagement and elicitation processes for diagram generation were highly appreciated. Through these processes, diagrams played a significant role in collecting different viewpoints of various stakeholders and putting complicatedly inter-connected system elements together. From the risk analysis perspective, diagrams were very instrumental in providing systems view while identifying and eliciting where risks could be, but limited in analysing the potential knock-on effects of the risks.

It was reconfirmed from the cases that different diagrams show different and limited views of the system. Different diagrams have different strengths in representing certain aspects of the system: medicine/information flows, decision-making steps or state-dependent system behaviour. However, choosing the most appropriate diagram type is not a straightforward decision, requiring the skilful balancing of pros and cons. It would be for the most part governed by the system or issue to be investigated, but consideration of the healthcare users must be important. Therefore, it is highly recommended that more than one diagram type should be used to describe a system to capture the complexity of the system. In case 3, healthcare stakeholders expressed a strong liking towards state-transition diagrams, partly owing to the patient-centred view of state-transition diagrams or event-driven nature of care processes. Further research with a broad range of healthcare contexts and a large number of healthcare users is needed to provide more definite evidence that diagrams lead to a better corporate understanding of systems by the stakeholders and therefore better quality.

The other area for further research is about the way to support healthcare users for diagram generation. Some of diagram types could be very challenging and time-consuming for healthcare users to generate, particularly without the appropriate guides and software. Therefore clear guidelines and examples on how to apply various general-purpose diagram types to healthcare-specific issues and systems are needed for wider use of diagramming in healthcare.

References

Clarkson, P.J., Buckle, P., Coleman, R., Stubbs, D., Ward, J., Jarrett, J., Lane, R. and Bound, J., "Design for patient safety: a review of the effectiveness of design in the UK health service", Journal of Engineering Design, Vol.15, No.2. 2004, pp 123-140.

Crilly, N., Clarkson, P. and Blackwell, A.F., "Graphic elicitation: using research diagrams as interview stimuli", Qualitative Research, Vol.6, No.3. 2006, pp 341-366

Edwards, N., "Can quality improvement be used to change the wider healthcare system?" Quality and Safety in Health Care, Vol.14, No.2. 2005, p 75.

Fowler, M. and Scott, K., "UML distilled: a brief guide to the standard object modeling language", Addison-Wesley London, 2000.

Friedenthal, S., Moore, A. and Steiner, R., "A practical guide to SysML: the systems model language", Elsevier/Morgan Kaufmann London, 2008.

Jun, G.T., Ward, J. and Clarkson, P.J., "Systems modelling approaches to the design of safe healthcare delivery: ease of use and usefulness perceived by healthcare workers", Ergonomics, In Press, 2010.
Pidd, M., "Tools for thinking: modelling in management science", John Wiley & Sons Chichester, 2003.
Pradhan, M., Edmonds, M. and Runciman, W., "Quality in Healthcare: process", Best practice & research. Clinical anaesthesiology, Vol.15, No.4. 2001, pp 555-571.
Purcell, A.T. and Gero, J.S., "Drawings and the design process", Design Studies, Vol.19, No.4. 1998, pp 389–430.
Smith, J., "Building a Safer NHS: Improving Medication Safety", Department of Health London, 2004.

Dr. Gyuchan Thomas Jun
Research Associate
University of Cambridge, Engineering Department
Trumpington Street, Cambridge, UK, CB21PZ
Telephone: 44-1223-748572
Email: gj225@cam.ac.uk
URL: http://www-edc.eng.cam.ac.uk/people/gj225.html