**Combining Soft Systems Methodology and Discrete Event
Simulation modelling for optimising hospital patient flow and
resource utilisation**

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Thesis for the degree of Philosophiae Doctor (PhD)

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List of papers

Paper I: Holm, L. B. and Dahl, F. A. 2011. Using Soft Systems Methodology as a precursor for an emergency department simulation model. *OR Insight* 24(3): 168-189.

Paper IIa: Holm, L. B. and Dahl, F. A. 2010. Simulating the effect of physician triage in the Emergency Department of Akershus University Hospital. In: *Rossetti, M. D., Hill, R. R., Johansson, B., Dunkin, A. and Ingalls, R. G. eds. Proceedings of the 2009 Winter Simulation Conference*

Paper IIb: Holm, L. B. and Dahl, F. A. 2010 Simulating the influence of a 45% increase in patient volume on the Emergency Department of Akershus University Hospital. In: *Johansson, B., Jain, S., Montoya-Torres, J., Hagan, J. and Yücesan, E. eds. Proceedings of the 2010 Winter Simulation Conference.*

Paper III: Holm, L. B., Lurås, H. and Dahl, F. A. 2012. A simulation model of hospital bed utilisation. With application to a 40% increase in patient volume in a Norwegian general hospital. *International Journal of Medical Informatics*, 82(2): 80-89. <http://dx.doi.org/10.1016/j.ijmedinf.2012.05.006>

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List of frequently used abbreviations

SSM	Soft Systems Methodology
DES	Discrete Event Simulation
OR	Operational Research
Ahus	Akershus University Hospital
ED	Emergency Department
CSU	Central Surgery Unit

Executive summary

Using research methods from both hard and soft paradigms in the planning phase of hospital interventions may increase the possibility for successful implementation. Hard paradigm simulation can be used for studying possible consequences of an intervention. Soft paradigm research is used for understanding the human behaviour towards a system. This thesis concludes with a description of seven criteria for a successful intervention as experienced in this research:

- a) Understand the real problem
- b) Understand the stakeholders' perspectives and purposeful activities
- c) Anchor the intervention among all stakeholders from the beginning and involve them closely
- d) Agree on feasible and desirable changes
- e) Explore possible quantitative consequences of the intervention before implementation
- f) Implement the solution successfully
- g) Ensure compliance with the implemented change

These criteria may be fulfilled with a combined use of methods from both hard and soft paradigms. This thesis demonstrates a successful real world hospital application of the combined use of Soft Systems Methodology (SSM) and Discrete Event Simulation (DES) in a multimethodological fashion. *Methodology* literally means *the science of methods*, but it has in recent years been increasingly used as a substitute for *methods* in scientific and technical contexts (Mingers 2000a). Mingers and Gill (1997, p. 1) define it as a “*structured set of guidelines for activities to undertake to improve the effectiveness of an intervention*”. They further refer to *multimethodology* as the combining of more than one methodology, in whole or part, often from different paradigms (Mingers 2000a; Mingers and Gill 1997). This is the terminology used in here. The aim of the thesis is twofold. From a theoretical perspective, the multimethodology of combining DES and SSM is the focus. In a more empirical perspective, the application of the multimethodology at Akershus University Hospital (Ahus) and results on patient flow and resource optimisation are studied. The main research question is:

- Can a combined use of SSM and DES be more useful than the additive effect of using each method successively within the same intervention in a real world hospital setting, where the aim is to improve patient flow and resource utilisation?

This is explored in three separate studies that in varying ways demonstrate how this can be successful. In the first study, which was carried out in the Emergency Department (ED) at Ahus, we used SSM as a precursor for a DES model (Paper I). The first aim of the simulation model was to evaluate the effect of an already implemented intervention where nurse triage was replaced with physician triage (Paper IIa). The second aim was to evaluate the resource needs in the ED following a 45% increase in patient volume at the hospital (Paper IIb). The

empirical results showed that physician triage would not significantly improve patient flow. It also showed that the patient volume increase could be successfully met with marginal increase in nurses and treatment rooms, but it required a 50% increase in physicians.

The study was partly successful. The initial SSM parts achieved solid anchoring of the study among stakeholders and an understanding of the actual problem and the stakeholders' purposeful activities. The simulation model achieved exploring of possible consequences of the intervention. The two methodologies were used successively (SSM as a precursor for DES), and we were not able to achieve an agreement on feasible and desirable changes after the simulation analyses. The results were therefore not applied successfully in this study.

In a study of hospital bed reallocation (Paper III), we were asked by the hospital management to develop a simulation model that would explore the best possible allocation of beds among the wards of the hospital. This was already an ongoing project when we got involved, and we were therefore not able to use SSM. A simulation model was developed in close cooperation with the stakeholders. The fundamentals for the model were anchored well among the stakeholders and the model was thoroughly validated and served well in exploring possible consequences of bed allocation. However, when the results were presented, a long and heated discussion followed. We had apparently failed in understanding what the real problem actually was as well as the purposeful activities of the stakeholders. Even though we thought we had reached a consensus of possible changes to the bed allocation, there were problems with the feasibility and desirability of the recommended changes. This led to an unsuccessful implementation of the simulation model results.

In a study at the Central Surgery Unit (CSU) (Paper IV), SSM and DES were used in combination. The background for the study was the patient volume increase from 2011. The empirical results from the study showed that there was

no critical bottleneck in the system. We were able to show that it is the sum of possible small delays in every activity performed by several actors before, during and after each surgical procedure that lead to delays and non-productive use of time. Suggestions for improvements with direct and indirect impact on surgical activity were proposed for the management, several of which were successfully implemented.

In the CSU study, SSM and DES were used in a combined way. With SSM we were initially able to anchor the study among stakeholders and reach an understanding of the real problem. We also developed an understanding for the different stakeholders' purposeful activities. With the simulation model we explored possible consequences of different interventions. These were thereafter discussed in an SSM-like fashion to agree on feasible and desirable changes. This ensured successful implementation of our suggestions for improvements. In the CSU study, all criteria for a successful intervention (a-g above) were thereby fulfilled. This supports our conclusion that when soft and hard paradigm methodologies are used in a combined way, an intervention is more likely to be successful.

1. Introduction

Operational research (OR) is the application of advanced analytical methods to help make better decisions. By using techniques to analyse complex situations, OR provides the power to make more effective decisions and build more productive systems. This is done based on more complete data, consideration of all available options, careful predictions of outcomes and estimates of risk, and with the latest decision tools and techniques (Informs 2012).

In general, OR techniques can be divided into two main streams: soft and hard OR. The aim of this thesis is two-fold. In a *theoretical perspective* the aim is to show how soft and hard OR techniques can work together in a multimethodological fashion, creating synergies that would not be obtained with the use of either technique alone. (See section 2.2 for definitions of *methodology* and *multimethodology*).

The combination of two such techniques, Soft Systems Methodology (SSM) and Discrete Event Simulation (DES), has led to the development of a multimethodology that has been applied at Akershus University Hospital (Ahus) in order to improve the patient flow and resource utilisation at the Emergency Department (ED) and the Central Surgery Unit (CSU) of the hospital and to prepare for an upcoming patient volume increase of 40%¹ due to a restructuring of the secondary care districts in Oslo and suburban areas in 2011. The *empirical perspective* of this thesis is to show specific implications at Ahus resulting from the application of our multimethodology.

¹ In 2009 it was not known exactly by how much the catchment area would increase in 2011. It was expected to be around 45% with a slightly less increase in patient volume. This expectation was later adjusted to 40%, which is the reason for the discrepancies in the expected patient volume increase between the papers.

2. Theoretical framework and related research

2.1 Operational research

Historically, OR emerged during World War II as a tool for optimising military decisions. Since then, it has grown into a large field of decision support techniques with military and civilian applications. Also, within health care, OR techniques have been widely used and in many areas OR societies have been established. ORAHS, for instance, is a society for operational research applied in health services (Brailsford and Vissers 2011; Orahs 2012).

Simulation and modelling are well-known OR techniques and have been widely used within health care (Brailsford et al. 2009; Brailsford 2005; Brailsford and Hilton 2001). This is shown by the large amount of literature and conferences with focus on simulation and health care. A recent literature review (Günel and Pidd 2010) shows that DES has been used in modelling health care systems for many years and that the number of papers published has increased markedly the later years. However, the generality of these papers is limited. The authors argue that most reported health care simulation studies are unit or facility specific, with the risk of missing the big picture. They therefore encourage future authors to focus on more generalisable issues with more focus on detailed conceptual descriptions of their approach, in order to permit others to reuse their approaches.

Our research group focuses on simulation and modelling in order to optimise resource utilisation and patient flow in our health region. The philosophy behind our modelling is similar to Jay Forrester's modeller commandment # 1 which states the importance of modelling a problem or an issue, not a system. Moreover, the parts or aspects of a system that are worth noting depend on the problem that one is addressing. Any general-purpose model of a system therefore tends to be unnecessarily detailed in some aspects and too crude in others. In addition to focusing on efficiency (i.e., building the

models only as detailed as necessary to answer a given research question), we also focus on building models that address relevant problems to which stakeholders seek answers.

This leads to another general problem within OR. Some OR communities have mainly been successful with technical optimisation problems of limited importance. They have had less impact on important complex problems in the real world (Ackoff 1979; Fildes and Ranyard 1997; Mingers 2000a; Pidd 2001). A main reason for this may have been that 'classical' hard OR methodology focuses on physical entities and hard facts, while human interaction is not emphasised. In complex real-world problems this is often a mistake, because human interaction is usually the key issue on two levels: First, the interaction among people in the system being studied is often a key ingredient in a model (Brailsford and Schmidt 2003; Brailsford et al. 2012). Second, for a model to be accepted by decision makers and affected parties, their views on the basic function and purpose of the system must be taken into account. Problem structuring methods are tools designed to accomplish this by capturing the perspectives and goals of the relevant parties, thus enabling researchers to develop reasonable models of human interaction in complex systems, where the underlying assumptions are accepted and agreed upon (Checkland 2000; Eden and Ackermann 2006; Mingers 2000a; Mingers and Rosenhead 2004). The soft methodologies favour engagement and participation over isolated technical modelling of a certain well-defined problem.

Several problem structuring methods have been described in the literature. Mingers and Rosenhead (2004) give an overview of this. The most frequently used soft OR technique has been SSM (Checkland and Scholes 1990; Kreher 1994; Ledington and Donaldson 1997; Mingers 2000a; Mingers and Taylor 1992). SSM is widely used within health care, and the most important reference to highlight is the research done by Checkland and colleagues in which the National Health Service was evaluated during the NHS centralisation process in

the 1980s (Checkland 2000; Hindle et al. 1995). Wells (1995) used SSM to analyse the nurse management and activity on a psychiatric in-patient facility, while Macia-Chapula (1995) used the methodology in a health care information system. Hindle and Franco (2009) describe a mixed methods approach in which they use SSM and causal mapping in a study concerning the implementation of medical standards on fitness-to-drive in the United Kingdom.

Over the last decade a combination of soft and hard OR techniques has been shown to be useful. When combining SSM and simulation modelling, staff will develop a sense of process ownership as they are involved with the study from the beginning. It further ensures transparency of the process and greater understanding and knowledge of their own systems, and it encourages the acceptability of the final simulation model and its output (Lehaney and Paul 1996; Lehaney et al. 1999; Lehaney and Paul 1994). One can go wrong with simulation models if one solely concentrates on the quantitative aspects of modelling without raising important issues early enough in the development of the models. This risk might be reduced when including SSM in the process (Lehaney and Hlupic 1995).

2.2 Multimethodology

Methodology literally means *the science of methods*, but it has in recent years been increasingly used as a substitute for *methods* in some scientific and technical contexts (Mingers 2000a). Mingers and Gill (1997, p. 1) define the term *methodology* as a “structured set of guidelines for activities to undertake to improve the effectiveness of an intervention”. Methodologies are based on particular philosophical assumptions regarding the organisational world and how various forms of action in this world are undertaken. Further, Checkland (2000) argues that SSM is a methodology rather than a method, because it is a flexible but structured inquiry into problems that is typically modified for each use. The

term *methodology* in this thesis, is used in the meaning of Mingers and Gill's interpretation.

Methodologies are characterised as *hard* (positivist) when the organisational world is treated as objective and *soft* (interpretivist) when the human organisations are treated as fundamentally different based on subjective meaning and interpretation. In addition, a *critical* paradigm is one that accepts the place of both hard and soft paradigms. These paradigms, and the methodologies belonging to each, are often said to be incommensurable. However, in the 1980s and 1990s researchers and practitioners began questioning this incommensurability and found that no one paradigm could capture the richness of real world situations, and so methodological pluralism became a point of debate in philosophy, social sciences and eventually in OR (Mingers and Gill 1997).

The term *multimethodology* refers to the combining of more than one methodology, in whole or part, often from different paradigms (Mingers 2000a; Mingers and Gill 1997). It is also referred to as *mixed methods research* (Niglas 2004), which might be more literally correct.

There are many possibilities for combining methodologies, and Mingers and Gill (1997) classify this combination across five dimensions. The first dimension is whether or not more than one methodology is used. The second dimension is whether the methodologies used come from the same or different paradigms and the third dimension specifies whether they are used within a single intervention. The fourth and fifth dimensions are whether the whole or parts of the methodologies are used, and whether a single methodology is given overall control.

Different names are given to the different types of methodology combinations (Mingers and Gill 1997, p. 7). *Multi-paradigm multimethodology* is the combination of parts of two or more methodologies from different paradigms used in the same intervention, where one methodology does not desire full

control but both methodologies are linked to form a multimethodology particular to that situation.

2.3 Applied multimethodology

Numerous organisations have been combining OR approaches over the past few decades. Given that multimethodology projects are seen in the literature more often than ever before, researchers and practitioners have been calling into question the use of a mere single methodology in OR settings (Mingers and Brocklesby 1997). The multimethodology literature is extensive, and only in the latest issue of *Journal of Mixed Methods Research* five case studies of multimethodology are presented (Petros 2012; Luyt 2012; Robinson and Mendelson 2012; Yu 2012; Teye 2012). Conclusions from these studies are that the application of a multimethodology research design can enable an enhanced understanding of the target issue as well as provide results that are more comprehensive than they would have been from a single method (Petros 2012). Multimethodology also provides an effective means of explaining the complexity, contradictions, and messiness of human behaviour; in short, it ensures a broader understanding of research problems and provides opportunities that are more robust for formulating policies that address social problems (Teye 2012). One of the most cited publications about mixing qualitative and quantitative methods is one by Jick (1979). He describes the different strategies for combining qualitative and quantitative methods. To explain his strategies, he defines *triangulation*, which means combining research from qualitative and quantitative perspectives. To demonstrate, he reports one of his case studies for which he used triangulation to measure anxiety and its dynamics in an organisation. He concludes that even though triangulation may not be suitable for all research purposes because various constraints may prevent its effective use, it has vital strengths and it does encourage productive research. It heightens qualitative methods to their deserved prominence and, at the same time, demonstrates that

quantitative methods can and should be utilised in complementary fashion. Triangulation can therefore stimulate us to define and analyse problems more clearly in organisational research.

Another highly cited, but more recent case study with a mixed methods approach is published in *Nature Genetics* (Yu et al. 2006). This study describes the development of a unified mixed-model approach where a combination of association mapping and genomic tools was used to uncover population structure and familial relationships. Their method demonstrates improved control of both type I and type II errors over other methods. Rocheleau (1995) is another highly cited multimethodology paper. This is a political ecology study of gendered interests in a social forestry program in the Dominican Republic. The study combined quantitative and qualitative data collection and analytical techniques. The study demonstrates that it is possible to reconcile multiple subjectivities and quantitative methods in the quest for objectivity. It also shows how one can possibly combine traditional positivist methods with participatory mapping and oral histories.

In a survey that they conducted in 2002 in the UK, Munro and Mingers (2002) asked OR practitioners to report on their use of multimethodology. The survey concludes that practitioners are using multimethodology more frequently than ever before and with much success, although multiparadigm multimethodology appeared less frequently than did combining methods within one paradigm. In contrast, Howick and Ackermann (2011) discovered a higher degree of multiparadigm than single paradigm multimethodology cases in their review. This literature review, which builds upon the lessons learnt by Munro and Mingers' survey, analyses published case studies in order to find generic lessons that might be associated with applying a multimethodology design. One of the recurrent themes is size of the research group. Should one practitioner have experience in both methods used, and if not so, how do practitioners from opposing paradigms cooperate? Another recurrent theme was the types of

method mixes: quantitative vs. qualitative, full or parts of methods combined, and the nature of the mixes (used in sequence, in parallel, or interacting with one another). The third common theme that Howick and Ackermann discussed in their multimethodology review is the nature of the intervention, which varied considerably depending on group size, the nature of the objective, the type of mix, and the duration and form of the intervention. The fourth issue discussed is that many of the papers included in the review did not explicitly discuss the client value of the intervention which was achieved by mixing methods. Furthermore, none of the papers made clear whether any of the benefits gained were the results of the mixing approach, the results of the individual methods, or the results of the intervention. The fifth and last issue that this review discusses is the rationale for applying a multimethodology design. Researchers do give ample, detailed reasons for their desire to mix methods, but they make few connections between their rationale and the actual outcome of the project. In addition, the majority of the papers avoided the multiparadigm debate. Howick and Ackermann argue that many researchers do not consciously articulate or reflect on their methodological decisions.

Both Howick and Ackermann (2011) and Munro and Mingers (2004) demonstrate that SSM is the predominant soft methodology used when methods are mixed, and simulation (mainly DES) is the most frequently used quantitative method. This thesis deals with the combination of SSM and DES in a health care setting, and the following section describes the literature related to the combining of these methods.

2.3.1 Combining SSM and DES in healthcare

A few studies described in the literature show the use of SSM and simulation in combination within health care. Lehaney and Paul (Lehaney and Paul 1996; Lehaney and Paul 1994) used SSM in the development of a simulation of out-patient services at Watford General Hospital. The authors considered the use of

the methodology as an aid to identifying relevant system activities, as simulation itself provides no methods for this. Lehaney and Hlupic (1995) provide a review of the use of simulation models for resource planning in the health-care sector and argue that SSM could be used to improve these processes. Lehaney and Clarke (1997) also discuss the advantage of combining simulation and SSM through a mixed mode modelling approach. Lehaney et al. (1999) report on a case intervention where a soft systems approach combined with simulation was used in an outpatient NHS dermatology clinic to address the gaps between the expectations of the customers and those of providers.

In a study of a health care system for older people in Kent, Kotiadis (Kotiadis 2006; Kotiadis 2007) uses an SSM approach to delineate the problematic situation into precise questions and objectives, which were then explored in a simulation model. Through a case study, Kotiadis and Mingers (2006) explore the benefits and barriers of combining SSM with DES within community-based intermediate care. By adding findings from an SSM process into the simulation models, they were able to build models that answered questions that were more important to the stakeholders. In summary, SSM has played a central role in the health care simulation studies presented above, mainly for communicating with stakeholders and for validation purposes. The main argument is that the participative nature of SSM increases the acceptability of the simulation model.

There are different ways of combining SSM and DES, as shown in the described literature. However, except for Kotiadis and Mingers (2006), who describe how both methods have been adopted at different stages of the study, few papers describe in detail how this combination has been performed and the subsequent application of the results. There is therefore a need for literature describing detailed processes of combining SSM and DES, or soft and hard OR, in a real world health care setting, and further describing the success and application of results from such studies. While most of the literature primarily describes how SSM is used as a preparation for simulation studies, this thesis

gives a detailed description of the development of a multimethodology in which DES models are developed as a part of an SSM process. The DES models are used as an integral part of the feedback to the agents participating in the SSM processes. The thesis also shows the specific implications at the hospital resulting from applying this multimethodology, and it indicates that the combined use of the two methods not only works better than the use of each method alone, but it also indicates to be better than successive use of SSM and DES within the same intervention.

3. Research Questions

The aim of this thesis is to show how hard and soft OR techniques, SSM and DES, can work together to improve patient flow and resource utilisation in a Norwegian general hospital. In a theoretical perspective, the aim is to describe the combination of SSM and DES and the development of our multimethodology. In an empirical perspective, the aim is to show specific implications at Ahus resulting from applying our multimethodology.

The overall research question is:

Can a combined use of SSM and DES be more useful than the additive effect of using each method successively within the same intervention in a real world hospital setting, where the aim is to improve patient flow and resource utilisation?

This is explored through three separate studies at the ED, the CSU and the ward areas of the entire hospital. The research questions for each of these sub-studies are investigated in five papers included in this thesis:

- Which plausible, relevant, purposeful perspectives and subsequent root definitions can describe the real world activities in the ED, and can a process of obtaining these function as a precursor for an ED DES model? (Paper I)
- How can the ED prepare for a 40% patient volume increase?
 - Does allocation of triage resources improve patient flow? (Paper IIa)
 - What will the main ED resource requirements be in 2011 after the patient volume increase? (Paper IIb)
- What is the best allocation of beds among wards to achieve the fewest number of crowding patient days for the hospital in total? (Paper III)
- How can the CSU prepare for the patient volume increase and where is the bottleneck? (Paper IV)

4. Material and Methods

Ahus provides the material for the research performed in this thesis. The first sections of this chapter will therefore give a short description of the hospital as a whole, and more detailed descriptions of the ED and the CSU, which have been central for this research. The second section of this chapter presents the research methods DES and SSM in more detail.

4.1 Akershus University Hospital

Ahus is a large public² university hospital situated a few miles northeast of Oslo in Norway. The hospital moved to new facilities in 2008, and after January 2011 the patient mass increased by approximately 40% due to a restructuring of the hospital districts of Oslo and the suburban areas. The hospital now operates with about 700 regular beds and is serving about 460,000 inhabitants, which represents almost 10% of the nation's population. In 2011, the number of employees was more than 8000, all with a fixed salary.

The hospital is organised into five clinical divisions including surgical, medical, paediatrics, women's health and psychiatry³. The hospital's four main tasks are patient treatment, research, education of staff, and education of patients and relatives. This is regulated by the law and applies for all Norwegian public hospitals. Ahus provides health care services within most somatic areas, psychiatry and drug abuse. In addition to the regular beds that are distributed among the different wards, the hospital has an Emergency Department (ED), a Central Surgery Unit (CSU), an Outpatients' Surgery Centre, an Intensive Care Unit (ICU), a Post Anaesthesia Care Unit (PACU), several outpatient clinics, some inpatient units located outside the site of the main hospital, and a patient hotel to accommodate the least severely ill patients.

² Most Norwegian hospitals are public. These are funded through activity based financing where 30% of the expected cost is paid according to activity (the number of patients treated and the patients' DRGs) while 70% come from a block grant. In 2002 the central government took over the responsibility for, and the ownership of, the public hospitals (Hagen and Kaarbøe 2012). Prior to this, the 19 counties were responsible for organising all institutional health services. Five regional health enterprises were established in 2002 (reduced to four in 2007) and the hospitals became separate enterprises. Ahus is a part of South-Eastern Norway Regional Health Authority.

³ The hospital also had a division for beds and nurses (Nurses division) from 2008 to 2010. This is described in Paper I.

4.1.1 The Emergency Department

In Norway, walk-in patients do not normally arrive at the hospital ED without first being referred by other healthcare institutions. Most patients will first go to an out-of-hospital emergency ward centre (called “legevakt” in Norwegian), where the least severely ill or injured patients are treated and sent home (Oslo Kommune 2012). Patients who need more extensive medical care are sent from the emergency ward centre to the hospital ED, either by ambulance or self transportation. Those patients are, therefore, more severely ill than the average emergency ward centre patient and would normally need hospitalisation. Because of the severity of illness in the hospital ED patients, “left without being seen” (LWBS) patients are relatively rare in Norwegian hospital EDs, and are therefore not discussed further in this thesis. LWBS, however, represents a significant problem in many countries (Johnson et al. 2009; Kennedy et al. 2008).

Long waiting hours in EDs is a worldwide problem (Cowan and Trzeciak 2005), and has been an issue since the early 1990s (Andrulis et al. 1991). In many cases, the time before a patient is examined or even met by a physician is unacceptably lengthy. The main causes for ED overcrowding are well known: hospital bed shortages, high patient illness severity, increasing patient volumes, shortages of examination space and staff and more (Derlet and Richards 2002). Problems with overcrowding and long waiting times in Norwegian EDs received much media attention in 2008 and 2009. To meet some of these concerns, the Norwegian Board of Health Supervision then explicitly stated that all Norwegian hospitals had to make the necessary changes to ensure that patients are seen by a physician as soon as possible after arriving at the ED.

From February 1, 2009, Ahus made organisational changes and expressed an ideal that the maximum patient waiting time for an initial physician evaluation upon arrival at the ED should be 10 minutes, and the maximum patient waiting time for a physician examination should not exceed 30 minutes. To comply with

these demands, the ED decided to replace the nurse triage with a physician triage during the busy hours of the ED, which are Monday through Friday from 10 a.m. to 7 p.m. An evaluation of this organisational change is described in Paper IIa of this thesis (Holm and Dahl 2009).

The ED of the hospital has two waiting areas, 15 standard treatment rooms, two trauma rooms, an observation area and a ward area for patients who are waiting for a room at another ward, waiting for results of tests, or expected to be discharged within 24 hours. The yearly average length of stay (LOS) at the ED of Ahus was 241 minutes in 2009 (Holm and Dahl 2010) and 212 minutes in 2010 (Ahus 2010). In January 2011 the patient volume at the hospital increased by approximately 40% as described in section 1. The challenges in high LOS and the expected patient volume increase in 2011 were the background for the studies presented in papers I, IIa and IIb in this thesis.

4.1.2 The Central Surgery Unit

There are two surgical units at Ahus: the CSU, which performs surgical procedures for in-patients, and the Outpatients' Surgery Centre, which handles all elective procedures for outpatients. The CSU has 14 operating theatres (OTs) in total, of which 10 were utilised at full capacity in 2010 (one was reserved for research, one for highly infectious patients, one as a buffer capacity for emergency scenarios, and one for acute Caesarean sections). Emergency surgeries are handled 24 hours a day, while elective surgeries are performed between 8 a.m. and 3:30 p.m. In 2009, CSU performed 8014 surgical procedures. This was increased to 8692 in 2010 and 10868 in 2011 (Ahus 2012). In 2012, CSU is expected to complete about 12000 surgical procedures. In addition to these figures, some 1000 expectedly simple inpatient procedures are being performed at the Outpatients' Surgery Centre in 2012 for capacity reasons.

The challenges of the CSU in facing the patient volume increase was the background for the research study described in Paper IV.

4.2 Simulation

Simulation is a well known operational research tool. A simulation model is a simplified computer imitation of a real world system with which one can experiment in order to understand and/or improve that system (Pidd 2004; Robinson 2004). Simulation models are often classified within three dimensions:

- Static or dynamic
- Deterministic or stochastic
- Discrete or continuous

While a static model represents a system at a specific point of time, a dynamic model includes the time dimension and changes to the system as time progresses. A deterministic model is a model that does not account for randomness, while randomness is accounted for in stochastic models. A model can be discrete or continuous depending on how the time parameter is handled. In discrete models, time progresses in steps between each change in variable state, while time is a continuous variable in continuous models (Banks et al. 2010; Pidd 2004; Robinson 2004).

The most used simulation methods are System Dynamics (SD) and DES, but there also exists a large body of other simulation modelling techniques; agent based models, microanalytical simulation models, multilevel simulation models, cellular automata, multi-agent models and learning and evolutionary models. These will not be discussed in more detail here; please refer to simulation textbooks for more information (for example (Gilbert and Troitzsch 2005; Law 2007; Pidd 2004; Robinson 2004)).

4.2.1 System Dynamics

SD models are dynamic, deterministic, and continuous simulation models. SD models include the time dimension and changes to the system while time

progresses. The state of the system changes continuously through time in SD models, and operations are not subject to discrete changes in state. Although randomness can be accounted for in SD models, this is generally not the case, and, in its purest form, an SD model represents a system of ordinary differential equations. SD models represent systems as a set of *stocks* and *flows* rather than a random activation of activities that change the system state in discrete time steps. *Stocks* are levels of resources accumulated through time while *flow* is what affects the resources flowing between stocks through time. *Feedback* is another central concept of SD models. Feedback loops are either positive/reinforcing loops or negative/balancing loops (Coyle 1996).

A project with an SD design often consists of both a qualitative stage and a quantitative stage. During the qualitative stage conceptual models are built as a means of transmitting mental models. The quantitative stage involves the mathematic implementation of the relationships derived from the qualitative stage (Tako 2008).

With SD models, one can study social or managed systems with the main aim of understanding a given system's behaviour. A researcher can consequently experiment with possible changes to improve the behaviour of the system (Tako 2008). In general, SD models look at the system as a whole and are particularly useful for looking at strategic issues within organisations (Robinson 2004, Tako 2008).

4.2.2 Discrete Event Simulation

A DES model is a dynamic, stochastic, discrete simulation model. It accounts for randomness, and time can be considered as a discrete variable where only the points in time at which the state of the system changes are represented. DES models are typically used for analysing systems at a strategic level. They facilitate a more detailed representation of a system compared to other simulation

techniques and are well suited for ‘what if’ scenarios in analysis where the aim is to improve the system capacity, resource utilisation or queuing time.

Central aspects in DES modelling are *entities*, *events*, *activities* and *attributes*. *Entities* are the objects flowing through the system—in this setting, the patients. *Events* are endogenous or exogenous occurrences responsible for the change in system, or entity state, which trigger the start of an *activity*. For example, the arrival of a physician triggers the activity ‘physician examination’. *Attributes* are qualities attached to the *entities*, for example, arrival patterns of patients. Other central concepts of DES modelling are the *event calendar*, which holds information of the state of all entities and stores the information of future events; the *simulation clock*, which keeps track of the simulation time and advances in discrete steps to the time of the next event in the calendar; and entity *queues*, which arise when there are not enough resources in the model to process the activities. The randomness of the model lies in the *random generator*, which provides *random draws* of activities from separate *probability distributions* (Banks et al. 2010; Pidd 2004; Robinson 2004).

4.2.3 The choice of DES

DES models are typically used for analysing systems at a strategic level and are well suited for ‘what if’ scenarios wherein the aim is to improve the system capacity, resource utilisation, or queuing time. In contrast, SD models are considered better for strategic analyses on a higher policy level, where the emphasis is on understanding the system’s structure and behaviour (Brailsford and Hilton 2001, Tako 2008).

DES models are frequently used for modelling health care systems and are well suited for studying the utilisation of hospital resources (Güna1 and Pidd 2010). In addition, the graphical interface of the DES software eases both communication with stakeholders and validation of the model.

The aim of the studies described in this thesis is to improve the patient flow and resource utilisation of specific departments at Ahus. This requires detailed dynamic models that account for randomness. We acknowledge that the level of detail in a model should never be more than necessary for answering the research question. The most detailed parts of the models in our studies are the arrival generators which include random variations in arrivals for each hour of the week following a poisson distribution. This is a very important detail that would be difficult to capture with an SD model. In addition, the number of patients arriving is relatively low and so is the number of resources (rooms, doctors, and nurses), so modelling a continuous flow would be too crude. A discrete approach was therefore necessary, and we chose to use a DES method for studying patient flow and resource optimisation in both the ED and at the CSU and for the bed allocation study.

There are several software tools available for DES modelling. We chose to build our models in FlexSim HealthCare®. This software is specially developed for health care modelling and it provides realistic 3D illustrations of objects in a hospital environment, as illustrated in Figure 1 below. It provides the possibility to quickly and intuitively create a system layout for a model with point-and-click simplicity. Extensive programming skills are not necessary for creating simple models. The 3D effects were shown to be very good for involving health care professionals (the clients) in the model building processes, for validation purposes and for presenting results. We also implemented some of the models in the statistical software R, in order to provide very long model runs. Implementing the same model in two different software packages also served a verification purpose.

Figure 1: 3D illustrations in FlexSim HealthCare ®

4.2.4 Verification and validation of simulation models

Verification and validation of a simulation model is important for the correctness and credibility of the model (Law 2009; Sargent 2009), and should be a significant element of any simulation study (Robinson 2004). Model verification is the process of ensuring correct implementation of the model in a computer program. Model validation makes sure that the model represents the system as accurately as needed for the particular objectives of the study (Banks et al. 2010; Law 2009; Pidd 2004; Robinson 2004; Sargent 2009).

Various forms of validation are described in the simulation literature. In *conceptual model validation*, the purpose of the study is important. One needs to validate the proposed model to see if it contains necessary details for the purpose of the study. Through *data validation*, one ensures that the data required for the model is accurate for the purpose of the study. While *white-box validation* ensures that the elements of the computer model correspond to the real world elements, *black-box validation* ensures that the overall model represents the real world with sufficient accuracy. Studying the etymology, in black-box validation one literally treats the model as a black box with no knowledge of the internal structure. In white box validation it is possibility to “peek inside the box” and study the internal structure of the content. The synonyms *behavioural validations* and *structural validations* are also used and might be more descriptive definitions.

The planned experimental procedures also need to be validated to be sure they will provide sufficiently accurate results in order to answer the research questions. This is called *experimentation validation*. Through *solution validation* one determines that the results themselves are sufficiently accurate (Robinson 2004). In addition, Banks (2010) describes *face validity*, which is the first goal of a modeller, namely to construct a model that seems reasonable at face value to the client. These different forms of validations (and verification) have been performed throughout the whole model building process in our studies.

Naturally, there are many difficulties with verification and validation of a simulation model. A model is only valid for its own purpose, and reusing a model requires a rephrasing of the objective and new validation towards this. Also, challenges arise when there is no real system with which to compare, and there might not be a consensus on which aspect of the real world comparison are relevant for. Another challenge is when the real world data are inaccurate. Even though there is never enough time to verify and validate all aspects of a model, it is important that modellers validate as much as possible, *in relation to the purpose of the simulation study* (Pidd 2004; Robinson 2004).

4.3 Soft Systems Methodology

SSM is a problem-structuring methodology developed in the early 1970s (Checkland 2000). Whereas hard OR focuses on the real world and believes it to be external and objective, soft OR, like SSM, addresses the conceptual world or the process of inquiry into the world (Checkland 2000). Within the conceptual world, it is possible to come closer to the understanding of how human beings are trying to take purposeful actions based on their own interpretations of a situation. This is an essential idea of the methodology.

Researchers may know SSM as the original seven step process shown in Figure 2 below. In this outline of the methodology, the steps are divided into parts related to the real world and parts related to the conceptual world.

Figure 2: The original seven step process of SSM (adapted from Checkland (2000))

In steps one and two the researcher perceives the problem situations and then tries to express it through a *rich picture*. These two first steps have their basis in the real world and emerge from actual real world situations. Steps three and four move away from the real world situation and towards *systems thinking about the real world*. In this conceptual world, *root definitions* and *conceptual models* are developed. **Root definitions** are descriptions of the system from different perspectives, or *holons*, as Checkland calls them. Root definitions can be viewed as definitions of the *purposeful activity system* relevant for exploring the problem situation. As an aid in developing root definitions, Checkland has developed the mnemonic **CATWOE**:

- **C**ustomers
- **A**ctors
- **T**ransformation
- **W**eltanschauung
- **O**wner
- **E**nvironment

The first to consider when using this mnemonic is the *transformation*. For each perspective of the situations in question it can be perceived as something that is transformed from input to output. After identifying the transformation, the *customers*, who are the ones that benefits from this transformation, and the *actors*, who are the ones that facilitate this transformation for the customers, can be identified. The *weltanschauung*, or world view, is the view from which the transformation is meaningful, and the *owner* is the ones who own the system, or to whom the system is answerable. The *environment* is what influences, but does not control, the system (Checkland and Scholes 1990; Williams 2005). To extend the perspective even further, the C could be replaced with a B for *Beneficiaries* and a V for *Victims* (which yields the mnemonic BATWOVE).

After identifying different perspectives and writing *root definitions*, these are incorporated into *conceptual models*, which is step four in the original SSM process. **Conceptual models** are also called **Purposeful Activity Models (PAM)**. Such models are not representations of anything in the real system as we normally understand the word ‘model’, but they are rather accounts of *concepts of pure purposeful activity* based on declared world views. They are used as devices to stimulate, feed and structure the debate about desirable and feasible changes in the real system (Checkland 2000; Kotiadis 2007). The key idea is that, at any given time, agents in a system will act upon their own interpretation of what is most purposeful, and this might not be what is purposeful for the system as a whole.

After conceptualising the problem situation by identifying perspectives, making *root definitions* and *conceptual models* of human purposeful activity, the next step is to compare these models to the real world to draw insights and determine ideas for improvements. In step five, **the conceptual models are compared with the real world**, usually through unstructured discussions, structured questioning of the model using a matrix approach, scenario or dynamic

modelling or by trying to model the real world using the same structure as the *conceptual model* (Williams 2005). In step six, **possible interventions are explored** and the *feasibility* and *desirability* of these interventions are assessed. In step seven, the last step in Checkland's original seven step process, **action to improve** the problem situation is taken.

SSM has evolved considerably over the years (Checkland 2000; Checkland and Scholes 1990; Mingers 2000b), the most important change being the essential understanding that the seven step process does not have to be followed rigidly. The methodology can be represented by two streams of enquiry: logic-based and cultural. While ***the logic-based stream of analysis*** is in some ways similar to the previously described original seven step model, ***the cultural analysis*** includes both social and political issues as well as the intervention itself. These three cultural analyses are called *Analysis 1, 2 and 3*. ***Analysis 1*** is an examination of the three roles in the intervention: the 'client' (the one causing the intervention to be made), the 'problem solver' (the one who wishes to do something about the situation) and the 'problem owner' (a group of owners, chosen by the problem solver, including the 'client', the 'problem solver', and other possible interest groups). ***Analysis 2*** is an examination of the social system, which is a continually changing interaction between the three elements, roles, norms and values. ***Analysis 3*** is an examination of the political or power related aspects of the problem situation. Analyses 1, 2 and 3 are not complete, or static, analyses but are dynamic aspects to evaluate and re-evaluate throughout the process.

Other minor improvements of the methodology seen in the 1980s include the ***five E's: efficacy, efficiency, effectiveness, ethicality and elegance***. These are all criteria by which the transformation (T) would be judged. An improvement in how to write a good root definition was also defined. By asking the questions *What to do (P)*, *How to do it (Q)* and *Why do it (R)*, a subsequent root definition can be stated: *A system to do P, by Q in order to do R*. Together with the *five E's*

and the *PQR*, the concepts *weltanschauung* and *holon* (perspectives) were also refined.

Aside from these minor alterations, two other significant changes to the methodology occurred in the 1980s. These were the distinction between mode 1 and mode 2 use of the methodology and the development of the “constitutive rules” for SSM (Mingers 2000a). While **Mode 1** is the typical traditional use of SSM by the seven step process normally done by an external researcher, **Mode 2** is a more flexible use of the methodology in which the concepts are used, but not in a standard way—for instance, by an internal person.

As the methodology became more and more flexible, the question ‘What actually constitutes the use of SSM?’ arose. The **constitutive rules** of SSM, developed by Checkland in the 1980s after this debate, consist of five propositions outlining the assumptions underlying SSM together with definitions of the main SSM concepts (Checkland and Scholes 1990, pp. 286-287):

- SSM is a structured way of thinking with the aim of bringing about improvements in a real world problem situation
- The methodology’s structured thinking is based on system ideas and its complete process has yielded an explicit epistemology (including the concepts *real world*, *systems thinking world*, *problem situation*, *analyses one two and three*, *rich picture*, *root definitions*, *CATWOE*, *the five E’s*, *conceptual model*, *comparison*, *desirable and feasible changes*, *action* and *the system to use SSM*)
- To claim to have used SSM the following guidelines must have been adhered:
 - No automatic assumption that the real world is systemic
 - Careful distinction is made between unreflecting involvement in the everyday world and conscious systems thinking about the real world

- Holons are constructed
- The holons are used to enquire into the real world
- Use of SSM needs to be characterised by conscious thought about how to adapt it to a particular situation
- Since SSM is a methodology, every use of it will potentially yield methodological lessons

As can be drawn from this, and emphasised by Checkland himself, SSM is a flexible methodology rather than a fixed method, and the seven steps are not usually followed rigidly (Checkland 2000). Having described all these changes in the evolution of the methodology, and when bearing in mind that SSM is a methodology and therefore a flexible way of structuring a problem situation by consultative use of guidelines and the SSM epistemology, we know that the use of the methodology should be experience based, and that it needs to be adjusted for each use to fit the particular problem situation. The *use of* the methodology is a learning cycle in itself. Our use of the methodology is described in papers I and IV. The methodology has been developed and fitted to our research and has eventually led to the development of a multimethodology in which SSM is used in combination with DES. This is the main result of this thesis and is described in the next chapter.

5. Development of the multimethodology

The focus of this chapter is to describe the development of our multimethodology, which is the main result of our research. In Chapter 6 the specific implications of applying the methodologies at Ahus is the focus.

In this research, SSM was first used in a study at the ED at Ahus. As previously described, the ED experienced a very long LOS in 2009 and 2010 and was at the same time preparing for a significant patient volume increase. SSM

was used as a precursor for a simulation model that was planned to be executed in order to estimate the resource requirements stemming from the patient volume increase. The use of SSM in this study is described in Paper I.

Before using the methodology in the ED we arranged a rehearsal workshop for volunteer researchers in our department. During this rehearsal we found out that CATWOE was too time consuming and difficult for the volunteers to fully understand. However, the PQR questions worked well for creating root definitions.

Some changes to the planned ED workshop were therefore implemented, and a full day workshop for nurses, physicians and management of the ED was arranged in a venue a few kilometres from the hospital. The attendees were grouped across professions to discuss different perspectives and create subsequent root definitions. The different root definitions were then presented and discussed in a plenary session, and together we worked towards an overarching conceptual model. In the second part of the workshop we began the flow charting for the simulation model.

After the workshop the researchers continued the work by creating an overall root definition and representing it in an overarching conceptual model. These were brought back to the ED health care professionals for discussion a few weeks later. The simulation model was also completed by the researchers after the workshop, although in close cooperation with the ED staff and management. A description of the simulation model, its aim and its results (papers IIa and b) is discussed in Chapter 6.

The experiences from the SSM and DES processes in the ED led to some changes in how we carried out our research at the CSU about a year later. As in the ED study, we based our contact and communication with the CSU's staff on the original seven step SSM process, initially expecting to use the insights gained as a precursor for the DES modelling of the unit. However, events took a different turn. Rather than building a model upon the information-yield from the SSM-

workshop we arranged with the unit, we ended up *simultaneously* developing and refining the DES model. We thus saw the contours of a multimethodology. SSM was not only used as a precursor for the simulation model, but the model development was done throughout the SSM process. This is described in Paper IV.

As with the ED, we arranged a full day workshop for health care professionals in an external venue. The perspectives, root definition, conceptual model and a draft of a simulation model were discussed. A major difference from the ED study was that in the CSU study we spent more time in the later phases of the methodology in which the conceptualised descriptions were compared to the real world and desirable and feasible actions for improvement were further discussed in a second workshop. The CSU study described in Paper IV is the main contribution towards the development of our multimethodology, which the remainder of this chapter will focus on.

In our multimethodology, the first steps of the standard SSM process are used to both understand and structure the problem situation, to anchor the study among the staff and as a precursor for the DES modelling. The DES model is then used during the last steps of the SSM process to define possible areas of improvement. An illustration of the processes in this multimethodology can be seen in Figure 3 (Figure 1 in Paper IV). This figure provides a schematic representation of SSM (top) and our multimethodology (shaded boxes). In addition, we have included a timeline for the multimethodology that outlines when and how we performed the various phases. The overlap between the shaded boxes, representing the multimethodology's logical phases, indicates that the methodology is non-linear, in the sense that, e.g., the DES-modelling was done in parallel with the other, more SSM-like phases.

Figure 3: Our Multimethodology

In **phase one** of this multimethodology, the standard SSM approach is followed: the problem situation is identified and expressed. Root definitions and conceptual models are developed in **phase two** in addition to drafting the flows for the simulation model. In **phase three**, we began developing and implementing the DES model in the computer program, drawing on the information obtained from phase two. As shown in Figure 3, the thinking about and development of the DES model is an ongoing process throughout phases 1 to 5. However, we think of it as an independent phase as well, in the sense that prior to this third phase, the DES has not interacted with the SSM process; i.e., it has been presented only abstractly. During this third phase, a first implementation is carried out in a programming tool, and this implementation is used in the later phases. **Phase four** of our multimethodology is where the conceptual world is compared to the real world. Here we compare the conceptions of the employees and stakeholders with the real world as captured in the DES. In addition, the stakeholders' ideas about the system are compared to observations, or measurements, of the system

as recorded by the modellers. In **phases five and six**, improvements that are both desirable and feasible are identified and discussed, and possible actions to improve the situation are described. In these latter phases, the DES model enters as an important tool for communicating with the CSU staff, and the model is iteratively refined and improved. Furthermore, the face validity of the model is greatly boosted by the stakeholders' direct involvement during this phase of development, and the DES model itself seems to influence the *desirability and cultural feasibility* of change—that is, the traditional sixth SSM step. A more detailed description of how the different phases of our multimethodology were carried out is described in Paper IV.

6. Synopsis of papers; application at Ahus

6.1 Paper I: Using soft systems methodology as a precursor for an emergency department simulation model

Which plausible, relevant, purposeful perspectives and subsequent root definitions can describe the real world activities in the ED, and can a process of obtaining these function as a precursor for an ED DES model?

This paper addresses the use of SSM in the initial phase of a simulation study performed at the ED at Ahus. The purpose of the study was first to identify and structure the problems in the ED for their own sake. Second, the use of this methodology helped identify factors that should and should not be included when building the simulation model.

The original seven step model of SSM was mainly followed. Observations, informal interviews and a full day workshop where all staff groups were represented, followed by further observations and informal interviews were used as research methods. A central idea of the methodology is that in any given

situation several different true perspectives exist. Understanding and structuring a problem situation require an understanding of all these perspectives.

A total of 10 ED perspectives emerged from this study. These were the perspectives of, respectively, the patients, the nurses, the physicians, the management and the patients' relatives. In addition, a work environment perspective and a patient logistics perspective were also discussed. Working in the ED for educational purposes, or research purposes, were also important perspectives. During the process we also observed an attitude towards the other wards of the hospital, which influenced the ED staff's perspectives towards their own tasks.

From each of these perspectives, root definitions were developed, and an overarching root definition and a conceptual model were created. In addition to the perspectives that evolved from the workshop, two taboo perspectives, which were not mentioned by the ED staff, are discussed in the paper. These were the importance of information and the perspective of looking at the ED from a commercial point of view, both for the hospital (*profit on patients* (in reference to footnote 2)) and for the employees (*salary*).

The second aim of this study was to identify factors that needed to be considered further for the simulation model. These were physical infrastructure, staffing, communication among staff, physical working conditions, patient waiting times and bed logistics. In the original seven step SSM process, the last two steps evaluate the desirability and cultural feasibility of changes and present action to improve the problem situation. These two steps are not discussed in the paper, since these would have to be done after the development of the simulation model.

This paper shows that SSM can work successfully as a precursor for building patient flow simulation models. Success criteria for this rely on the opportunity for the researchers to have full access to the field for observation and informal interviews with staff and management, time and resources to perform a

workshop where all staff groups are presented for at least one full day, and commitment from both staff and management throughout the whole process.

6.2 Paper IIa: Simulating the effect of physician triage in the Emergency Department of Akershus University Hospital

How can the ED prepare for a 40% patient volume increase?

Does allocation of triage resources improve patient flow?

The three main resources of the ED at Ahus are doctors, nurses and treatment rooms. In 2009, a structural change in these resources was implemented in which the nurse triage was replaced by physician triage. The reason for this structural change was to decrease the average LOS in the ED, both because physicians could reject the least ill patients, especially in peak time, and because one more nurse resource would be released to perform nurse examination of patients. Another reason for replacing nurse triage with that of a physician was to ensure that each patient is seen (briefly) by a physician as early as possible.

The paper describes the development of two simulation models, one representing the situation where nurses perform the triage and one representing physician triage. The results from the two models and comparable estimates from the electronic patient database are shown in Table 1 below.

Simulation models	Nurse triage model	Physician triage model
Waiting time from arrival to first meeting with physician	117	26
Waiting time from arrival to physician examination	117	110
Waiting time from arrival to nurse examination	55	33
Waiting time from arrival to discharge from ED	297 (278.76 – 297.24)	288 (287.50 – 306.50)
Actual waiting time (electronic patient database)	Before the implemented change	After the implemented change
Waiting time from arrival to first meeting with physician	126	Not available
Waiting time from arrival to physician examination	126	117 (p=0.302)
Waiting time from arrival to nurse examination*	141*	75* (p=0.251)
Waiting time from arrival to discharge from ED	281	268 (p=0.260)

Table 1: Patient waiting time in the nurse and physician triage model and actual patient waiting time from electronic patient database before and after implementing the triage change.

* These figures are very imprecise as they are based on the time when changes were initially made in the patient records, which is not necessarily equivalent with the actual beginning of the examination.

The results show that the only significant decrease in waiting times is the time patients wait for their first meeting with a physician, which was a goal in itself. The conclusion is, therefore, that changing from nurse to physician triage does not improve patient flow other than the change itself.

6.3 Paper IIb: Simulating the influence of a 45% increase in patient volume on the Emergency Department of Akershus University Hospital

How can the ED prepare for a 40% patient volume increase?

What will the main ED resource requirements be in 2011 after the patient volume increase?

Due to a restructuring of the hospital districts in Oslo and its greater metropolitan area, Ahus increased its catchment area from 340,000 to 460,000 inhabitants after January 2011. Following this the patient volume increase through the ED was initially expected to be 45% (please refer to footnote 1).

This paper describes 10 scenarios of resource increase, based on clinical relevance and systematic experimentation, and how these are evaluated in our ED simulation model. We wanted to estimate the lowest number of additional resources needed in the ED due to the patient volume increase, without compromising the patient flow. Table 2 shows the results from each scenario.

	Baseline	A	B	C	D	E	F	G	H	I	J
Beds	17	17	25	17	17	17	17	17	17	17	17
Nurses	8	8	12	12	10	8	8	8	8	8	9
Physicians	8	8	12	12	12	12	10	12	10	10	12
Triage nurses	2	2	3	3	3	3	3	2	2	2	2
Triage physicians	2	2	3	3	3	3	3	2	2	3	2
Time to complete activities:											
Time from arrival to nurse triage	32	366	29	44	43	42	88	48	95	92	44
Time from arrival to physician triage	22	219	19	37	36	35	49	38	49	50	38
Time from arrival to physician exam	188	542	174	175	176	174	227	177	233	231	177
Total time in ED	238	593	229	230	231	229	278	232	284	283	232
Utilisation:											
Regular nurse	31%	43%	31%	31%	36%	43%	43%	43%	43%	44%	40%
Regular physician	56%	73%	58%	58%	58%	58%	65%	58%	65%	65%	58%
Triage nurse	45%	47%	33%	33%	33%	33%	33%	46%	47%	47%	46%
Triage physician	47%	46%	33%	33%	33%	32%	32%	47%	47%	32%	47%
Bed area	45%	91%	42%	56%	56%	56%	65%	56%	66%	66%	56%

Table 2: Patient waiting time and staff utilisation in 10 scenarios of resource increase following an expected 45% increase in patient volume

Scenario G seems to be the most cost effective scenario with only an increase of four regular physicians. However, in this scenario the regular nurse utilisation is increased considerably. Therefore, scenario J seems to be the best scenario, considering both results in waiting times and staff utilisation given the described resource increase.

Increasing the nurse capacity from eight to nine nurses and the physician capacity from eight to 12 physicians seems to be sufficient to meet the needs following the 2011 patient volume increase.

6.4 Paper III: Improving hospital bed utilisation through simulation and optimisation. With application to a 40% increase in patient volume in a Norwegian general hospital

What is the best allocation of beds among wards to achieve the fewest number of crowding patient days for the hospital in total?

Due to the significant patient volume increase, Ahus increased its bed pool by 188 beds in January 2011. As a result of not knowing the health determining patterns of the new population, the initial distribution of the new beds among wards of the hospital was suboptimal, which led to an overcrowding of certain wards. A reallocation of the hospital beds was therefore necessary, and the hospital management initiated a project with the aim of estimating the best possible allocation of beds among the different wards of the hospital in order to keep the prevalence of crowding beds at a minimum. Crowding beds is the use of additional beds when all regular beds in a ward have been occupied.

This paper presents the development of a general bed utilisation DES model, and the application of the model to Ahus to improve the bed utilisation issues described above. Arrivals are modelled separately for acute and elective admissions with Poisson-distributions with time-varying intensity. The wards are of different sizes and each ward has separate length-of-stay distributions for acute and elective admissions. The model logs the number of patients at each ward through the simulation period. Based on model output, we have developed

algorithms that minimise either the average prevalence of patients in crowding beds or the incidence of admittances to crowding beds.

Intuitively, both prevalence (average number of crowding beds in use) and incidence (number of patients placed in crowding beds) might seem like relevant optimisation criteria. However, our experiments show that prevalence optimisation offers more sensible solutions than incidence optimisation, as the latter tends to sacrifice entire wards where length of stay is long and patient turnover slow. This can be seen in Table 3 below. Prevalence optimisation was therefore used.

Ward	1. Baseline Bed distribution			2. Prevalence optimisation			3. Incidence optimisation		
	Bed distribution	Yearly number of crowding patient days	Occupancy rate	Bed distribution	Yearly number of crowding patient days	Occupancy rate	Bed distribution	Yearly number of crowding patient days	Occupancy rate
Neonatal	23	522	96 %	24	389	92 %	0	8 042	∞
Children	30	248	86 %	28	446	93 %	36	26	72 %
Gastro medicine	18	665	101 %	20	362	91 %	26	30	70 %
Birth and maternity	57	151	78 %	48	824	92 %	67	9	66 %
Gastro surgery	77	3 539	110 %	90	960	94 %	110	28	77 %
Gynaecology	13	296	85 %	13	296	85 %	19	19	58 %
Haematology	19	499	96 %	20	364	91 %	26	30	70 %
Endocrinology	7	371	99 %	8	228	87 %	11	37	63 %
Cardiac Medicine	73	1 157	99 %	76	729	95 %	93	15	78 %
Infection	43	1 347	104 %	47	647	95 %	58	32	77 %
Vascular/thorax surgery	34	2	54 %	20	505	92 %	0	6 740	∞
Pulmonary medicine	48	2 808	115 %	58	640	95 %	0	20 091	∞
Neurology	84	1 108	98 %	86	823	96 %	100	48	83 %
Nephrology	19	320	90 %	19	320	90 %	0	6 212	∞
Orthopaedics	72	2 013	104 %	79	845	94 %	96	32	78 %
Urologi	32	157	77 %	27	561	91 %	38	20	64 %
Ear Nose Throat Stby	19	5	41 %	11	347	71 %	24	0	32 %
Ear Nose Throat Nbh	14	8	51 %	8	298	90 %	14	8	51 %
Ski short	8	327	95 %	9	200	84 %	0	2 761	∞
Stensby	28	405	91 %	27	530	94 %	0	9 301	∞
SUM	718	15 945	93 %	718	10 313	93 %	718	53 482	93 %

Table 3: Bed distribution results: This table shows the results from three analyses: 1) Baseline bed distribution, 2) Optimal bed distribution based on the prevalence algorithm and 3) Optimal bed distribution based on the incidence algorithm. The yearly number of crowding patient nights and average occupancy rate is presented for every ward, and for the hospital in total, for each of the three analyses.

The main results show that when the bed distribution is optimised, the share of crowding patient days is reduced from 6.5% to 4.2%. The wards that subsequently had to give up most beds according to a prevalence optimisation were Vascular/thorax surgery (-14), Ear Nose Throat (-14), Birth and maternity (-9) and Urology (-5). The wards that would receive most beds were Gastro surgery (+13), Pulmonary medicine (+10) and Orthopaedics (+7).

6.5 Paper IV: Towards a Multimethodology in Health Care – Synergies between Soft System Methodology and Discrete Event Simulation

How can the CSU prepare for the patient volume increase and where is the bottleneck?

The methodology of the study presented in this paper is based on experiences from the ED studies described in papers I, IIa and IIb. In this paper we further developed the combined use of SSM and DES. The initial aim of the study was to prepare the CSU at Ahus for the expected increase in activity from 2011.

The paper describes the development of our multimethodology and presents the results for the unit. The initial SSM parts of the process achieved an anchoring of the study among the staff and management at the unit by including them in the design of the study and defining the research questions. It further achieved including them in the initial model building process, and detecting mechanisms vital to the DES model itself, thus facilitating the development of a valid and realistic model. The DES model was used in later SSM parts of the study to detect possible areas of improvement.

Unexpectedly, the process revealed no critical bottlenecks in the system, but identified several *non-technical* problem areas, e.g. within communication, teamwork and team leadership. Suggestions for improvements were provided to the stakeholders, and the desirability and cultural feasibility of these suggestions were discussed.

Main suggestions for improvements with direct impact on the surgical activity:

1. Increase the daily throughput by increasing the efficiency during and between surgical procedures
2. Increase from 10 to 12 OTs
3. Increase the elective operating hours of each OT
4. Decrease the number of low activity weeks

Main suggestions for improvements with indirect impact on the surgical activity:

- a) Define a team leader and accommodate for teamwork
- b) Improve communication and cooperation among staff groups
- c) Synchronise work schedules of staff groups

With the changes suggested from this process, the CSU was expected to be able to meet the patient volume increase in 2011. This paper also demonstrates that the interaction between the two tools, SSM and DES, works well, creating synergies that would not be obtained with the use of either method alone.

7. Discussion

The aim of this thesis has been to show how two methodologies based on opposite paradigms, soft and hard, can be combined successfully in an actual hospital setting as a means for organisational planning for patient flow and hospital resource optimisation. Paper IV is an overarching paper with a main aim close to the aim of this thesis. Some parts of this discussion will therefore resemble the discussion in Paper IV.

This chapter is structured as follows. First, the study design is discussed in section 7.1. Section 7.2 and 7.3 discuss the two methods, SSM and DES, separately, and then 7.4 address the developed multimethodology. In section 7.5,

the specific results from Ahus, the limitations of each of the five papers, the resulting degree of implementation, and future implications resulting from this are discussed. Last, section 7.6 concludes with a general discussion in relation to the literature. Section 7.6 provides an overall general discussion, and here I provide a table that summarises seven key statements, or criteria, for a successful intervention. As an introduction to this table, I have throughout this chapter highlighted these key statements with bold face.

7.1 Study design

While the design of every study presented in this thesis was planned prior to their initiation, the overall study design of this thesis was not planned in advance. In retrospect, it is easy to see that the overall study design resembles that of an action-research design where the researcher interferes with and possibly affects the research field and where the research questions arise as the research progresses. In general, this thesis can be viewed as having an overall design of action research combined with qualitative case study methodology wherein each case study has a typical operational research design.

7.1.1 Action research

Kurt Lewin is widely recognised as the founding father of action research (Peters and Robinson 1984; Holter and Schwartz-Barcott 1993; Whyte 1991). A variety of approaches, definitions, and uses have emerged since action research's origin (Holter and Schwartz-Barcott 1993), so a universally accepted definition does not yet appear to exist in the literature. Action research is used in many disciplines and is particularly relevant in healthcare settings (Malterud 1995; Koch & Kralik 2006).

The main idea behind action research is to bridge the gap between theory, research, and practice. Collaboration between researcher and practitioners in diagnosing problems, designing action plans, and implementing these actions in

order to solve practical problems are the central functions of action research (Holter and Schwartz-Barcott 1993). This type of research further involves the process of actively participating in an organisational change situation whilst conducting research, so it is also known as Participatory Action Research (PAR) (Potvin et al 2010; Whyte 1991).

The four characteristics that are central to action research according to Holter and Schwartz-Barcott (1993) fit well with the research described in this thesis. Firstly, there has been active collaboration between researchers and practitioners to the extent that the stakeholders and the researchers have interacted significantly in all case studies. In action research, the stakeholder is seen as the expert for the given situation and setting under study, and the researcher is the outsider and a novice regarding knowledge of the local situation. The second characteristic of action research involves finding solutions to practical problems. All of the case studies herein aim to find feasible and desirable solutions to practical problems regarding patient flow and resource utilisation at the studied hospital. After finding solutions to practical problems, the next main goal of action research is to create change in practice. This goal is also the third characteristic of action research. Our research at Ahus has led to some change in practice, which we discuss further in section 7.5. The development of theory is the fourth characteristic and ultimately the final goal of action research. Although theory development has not been a central theme of the present research, the described multimethodology development is a result of the research performed for each of the case studies performed at Ahus.

Potvin et al (2010) describe action research as “knowledge in the making”. When theorists use the term “knowledge in the making” in conjunction with the term ‘research’ as the scientific activity of producing empirical knowledge, they are referring to knowledge that is produced in real time while the researchers study an intervention as well as actively participate in the organisational change. This term reflects how the overall research question of the present thesis arose as

the research progressed, and the as researchers gained more experience in the methods used.

7.1.2 Multi-paradigm multimethodology

Multi-paradigm multimethodology is the combination of parts of two or more methodologies from different paradigms for use in the same intervention. However, since a paradigm is itself reality-constituting and shapes the way we experience and deal with reality, some argue that soft and hard methodologies are incommensurable. Proponents argue that multimethodologic research *is* possible, but that it requires users to be skilled in several methodologies and to be able to work in a variety of paradigms (Mingers and Gill 1997). We argue that multiparadigm research does not require that a positivist, as an example, abandon his world-view, as long as there is a willingness to accept that the views of different agents form part of the external world being studied. This is the approach of a pragmatic positivist. Cooperation between soft paradigm and hard paradigm *researchers* can be very challenging, perhaps even impossible, if one or the other do not at all accept the views of the opposing paradigm. This does not necessarily imply, however, that the respective paradigm's *methods* cannot be fruitfully combined (Niglas 2004). In particular, if a researcher from a hard paradigm with experience in SSM is willing to pragmatically entertain the interpretivist's point of view, this should be sufficient for the efficient application of the multimethodology.

Peter and Robinson (1984) describe how Kurt Lewin rejected positivist beliefs and argued that science is characterised by a logically unique body of concepts; thus, Lewin held that scientists can objectively research social phenomena. Action research is therefore characterised as neither positivist nor interpretivist in nature; a pragmatic, positivist perspective is more correct for describing this view.

In the studies presented in this thesis, the researchers have experience in both simulation modelling and SSM, which was the key to success. The members of the research group that has contributed to the research that forms the basis of this thesis can all be characterised as originally hard paradigm researchers. However, three of us have spent considerable time learning about problem structuring methods because we too began to understand that it is impossible to capture the richness of real world situations with methods from only one paradigm. This is what researchers in philosophy and social science have long understood (Mingers and Gill 1997), and what OR researchers are just now beginning to accept.

7.2 Soft Systems Methodology

SSM was initially developed in the early 1970s by Peter Checkland at Lancaster University and was originally presented as a seven step process, as shown in Figure 2 in section 4.3. Over the past decades the methodology has evolved considerably (Checkland 2000; Checkland and Scholes 1990; Mingers 2000b) as described in section 4.3. It is now considered a flexible and open problem structuring method.

In a special issue of *System Practice and Action Research* honouring the work of Checkland, Mingers (2000b) describes SSM as an idea ahead of its time. The birth (in the 1970s: the seven step process, root definitions, CATWOE, conceptual models), childhood (1980s: the 5 E's, PQR, analysis 1, 2 and 3, Mode 1 and Mode 2 use, the constitutive rules) and the maturity (1990s: dissemination and diffusion of SSM) of the methodology are described. In addition, Mingers discusses some of the limitations of SSM. His first critique is that the development of SSM has been a closed and inward-looking world at Lancaster. Even though Checkland describes the use and development of SSM as a learning cycle, experiences from other disciplines, or practitioners outside Lancaster, are not included in the development of the methodology. Also, at Lancaster, SSM has not

been used in combination with other approaches, contrary to the use of SSM outside the Lancaster world.

The second important critique discussed by Mingers (2000b) is that Checkland claims that the concept 'system' should only be seen as epistemological (a mode of conceptualising – a soft paradigm) rather than ontological (existing in the world – a hard paradigm). This is, according to Mingers, a drawback for systems thinking as a whole. This might also be the reason for why SSM, according to Mingers, has not previously been used in combination with hard OR techniques at Lancaster. In our research we have used SSM in combination with a hard OR technique. We argue against the incommensurability of combining methods from two opposing paradigms as discussed in section 7.1.2.

An essential aim of SSM is to understand how human beings are trying to take purposeful actions based on their own interpretations of a given situation. This aim resembles the original theory behind action research, because the theory assumes that individuals' social behaviour can be considered a function of their social perceptions. Lewin argues that a researcher's task is to discover the meanings that actors give to events while they are acting (Peters & Robinson 1984), and SSM can be considered a method for extracting this meaning.

7.2.1 Our use of Soft Systems Methodology

The intention for the ED study was to use SSM as a precursor for the simulation study we were planning to do. This is described in Paper I. We wanted to be sure that the problem we were to investigate was in fact a real problem. Technically elegant simulation models are not useful if they do not **address the real problem**. In the literature, this is referred to as the error of the third kind (Mitroff and Featheringham 1974). Reducing the risk of type one errors (rejecting the null hypothesis when it is true) and type two errors (falsely accepting the null hypothesis) might not even be relevant if there exists a type three error of solving

the wrong problem. It could, e.g., be that the challenges facing the ED were due not to the number of primary resources (doctors, nurses and treatment rooms) but to a profession conflict. In fact, during the initial observation period, we experienced a lot of “blaming the other professions”, not only in the ED study but also in the CSU and in the bed distribution project group.

It is important to **understand the different stakeholders perspectives and their subsequent purposeful activities**. This is a main concept behind SSM (Checkland 2000). After a few weeks of the observation period in the ED, we became increasingly certain that a problem structuring approach would be beneficial for the ED project, and the SSM study was initiated.

For increasing the probability of results from a study to be successfully implemented, in addition to ensure studying the real problem, **anchoring the project well among the stakeholders and involving them closely** throughout the whole study period is also necessary. This is thoroughly discussed in the literature, for example in (Harper and Pitt 2004; Lehaney and Paul 1996; Lehaney et al. 1999; Lehaney and Paul 1994; Wilson 1981). During the workshop described in Paper I, we were surprised by how little the participants knew about each other. The physicians, the surgeons, the nurses, the management, the logistics and the cleaning personnel were all rather unfamiliar with the tasks and responsibilities of the others, so we found it important to spend some time getting the different profession groups to first learn more about each other. Even though this is not the usual format of an SSM process, it was very useful for the identification of possible problem areas.

For the ED, we were planning to continue with steps six and seven of the methodology after development of the simulation model. Unfortunately, this was not possible due to internal restructuring of the management in the ED. This was not due to our interference with the ED, but still might be a critique of our study. The initial steps of the methodology ensured anchoring the study well among the staff and management, but since the management of the ED was changed during

the study period and we did not involve the new management closely enough, the implementation phase was challenging. The specific results and the implementation are discussed in Section 7.5.

After the ED study, the head of the CSU approached me and asked if we could do a similar study in the CSU. This is described in Paper IV. This setting was slightly different, as it was initiated by the managers of the unit themselves, contrary to the ED project, which was initiated by the researchers. More resources were therefore available. We arranged a workshop with the same format as the ED workshop. In this study we also had the opportunity to arrange one additional workshop after the simulation model was developed. In this workshop we were able to discuss the results from the simulation model in order to compare the findings from the first workshop with the real world as captured in the DES model. This represents step five in SSM.

We were also able to **discuss changes that were both desirable and culturally feasible** (step six) **and agree on possible actions to improve the situation** (step seven). For an intervention to be successfully implemented, it is important that the suggestions for change are grounded in the working lives of the people who are influenced by the change. In our CSU study, this was ensured through the last two steps of SSM, which were carried out in the second workshop.

7.3 Discrete Event Simulation

Simulation models, when well made, allow us to generate systematic **predictions of future consequences of possible changes**. In a hospital environment it is easier, cheaper and, most important of all, safer to experiment in a computational representation of that environment rather than directly in the clinic.

The advantages of simulation over other modelling techniques are many. First of all, simulation provides the opportunity to model variability in detail. In

modelling, assumptions always have to be made, but with simulation these assumptions are often fewer and more accurate than in other modelling approaches because of the possibility to model variability and details closer to real-life situations. This was important in our studies. The variability in patient arrivals and LOS needed to be modelled with a level of detail close to real life in order to estimate optimal resource utilisation. A DES approach proved to be very useful for this purpose.

The transparency of a simulation model is another advantage. DES program developers have taken this one step further with advanced 3D graphics. This made our communication with stakeholders easier. Simulation studies also provide a necessity for detailed thinking about the problem, which in itself can be helpful (“a problem well stated is a problem half solved”, noted Charles F. Kettering).

When we discussed the details of the model with the stakeholders, they became more aware of how things were actually done in their department, which was not always how things were intended to be done. This might have had an influence on them, although we did not follow up on that.

There are also some disadvantages with simulation that must not be ignored. Software is expensive and modelling processes are time consuming. As this research has been an externally funded PhD project, the time and resource issues did not represent a problem. Another challenge with simulation modelling is that most models require considerable data to make appropriate assumptions in order to provide valid results. For many of our assumptions we were able to use data from the electronic patient database from many years back, although these had to be supplemented with subject matter expert opinions and manual registration surveys in some areas.

Simulation modelling also requires expertise in many areas: computer programming, validation, statistics, as well as in working with people. Our resource group had expertise in all of these areas, which was an advantage. Some

argue that a well presented and animated computer simulation model might provide overconfidence in the model (Robinson 2004). This might be true, but when we included the stakeholders in the model building process, they were aware of the assumptions and limitations of the model, and this reduced the risk of overconfidence. In our research we have also been clear with stakeholders and decision makers that our simulation models are decision support tools, not decision tools.

One of the most important aspects of simulation modelling is ensuring an accurate model. We spent a lot of time on validation and verification processes. Verification was ensured by careful and systematic implementation of the model in the software. Subparts of the models were run whenever a new process was added to ensure that the final models were correct. Researchers in our department who had extensive programming skills studied the underlying codes carefully, and in problematic situations we received valuable support from the software developers. It was an advantage that I personally attended a course at FlexSim, and that we have had regular contact with the developer of the program. In the bed allocation study, verification was also ensured by implementing the model using two different types of software; FlexSim HealthCare® and R.

In both the ED and CSU projects, the simulation models were developed in close cooperation with unit staff and management. This ensured the *face validity* of the model. *Conceptual model validation* made sure that the proposed model contained details necessary for the purpose of the study. This was warranted through the initial SSM phases of the studies. Both the subparts (*white box validation*) and the whole model (*black box validation*) in each study were extensively validated against real data from the electronic patient database. The models, in whole and in part, were run several times, and the outputs were compared to both input and data from the database.

The different model experimentations were planned and discussed with the units to ensure results that answered the specific questions of both the unit management and the researchers (*experimentation validation*). The final results were discussed with the staff and management of the unit to ensure that the results were sufficiently accurate (*solution validation*).

Data validation involves whether the data required for the model is accurate for the purpose. One challenge with building valid simulation models in our studies was the limited data quality. The electronic patient database provided information of some of the processes included in the models. For the arrival generator, the data from the database was sufficiently accurate. Also, for the black box validation the real world database served well as validation material. However, for some of the other processes, these data had to be supplemented with SME estimates and registration surveys.

The accuracy of SME estimates has been investigated in a separate paper (Holm and Barra 2011) not included in this thesis. The paper describes how SME estimates might be biased because SMEs often confuse the difference between mean and mode. In addition, the paper shows that beta distributions based on SME estimates outperform the more frequently used triangular distributions. We have, therefore, used mostly beta distributions based on carefully collected SME estimates in our simulation models. In the CSU study, we quickly realised that the data collection would be a challenging task. As Figure 3 in Paper IV shows, the link between the processes involved in a surgical procedure is complex and non-linear. This made it difficult to represent the real world in a simulation model, and therefore required extensive black and white box validation.

7.4 Our multimethodology

Papers I, IIa and IIb describe the use of SSM and DES in a study of the ED at Åhus. Paper IV describes the combined use of the two methods at the hospital's CSU. Altogether, combining SSM and DES worked well in these studies; in the ED, SSM

worked as a precursor ensuring that all relevant activities were included in the model, and in the CSU, SSM worked both as precursor for the model and as a means for agreeing on the way to proceed after discussing the simulation results.

The experiences from the two studies eventually led to the development of our multimethodology as shown in Figure 3 in Chapter 5. The first four steps of the original SSM process are used to understand and structure the problem situation, to anchor the project among the staff on the floor and the management of the unit and as precursors for the DES model. The first parts of the SSM process were also valuable in going from the complex description of the system (Figure 3, Paper IV) to the flowchart (Figure 4, Paper IV), which was finally implemented in the modelling software. The flowchart of the model, and the implemented DES model itself, was used in the last steps of the SSM process to define possible areas of improvement. We chose to represent our multimethodology as five distinct phases, shown in Figure 3 in Chapter 5. Some of these phases overlap and indicate that the methodology is non-linear; e.g., the DES-modelling was done in parallel with the other, more SSM-like phases.

As described in the first sections of this discussion, combining methodologies from hard and soft paradigms can be difficult, especially if there are researchers from different paradigms working together. We argue, however, that it is possible to combine methods from different paradigms, as long as the researchers are able to work across paradigms. We have shown that we were able to do so in the ED and the CSU study. The main challenge in the ED study was in the implementation phase, while the main challenge in the CSU project was in the complexity and non-linearity of the processes involved in a surgical procedure, which was challenging to represent in a simulation model. This would not have been possible to do without close interaction with staff and management through the SSM processes.

7.4.1 Group model-building

Group model-building refers to the process of involving stakeholders in model construction. The goal of involving them is to increase insight into the problem, to create alignment, and to develop a robust strategy for improving the organisation (Vennix 2012). Group model-building is mainly known within SD, and it is especially suitable for modelling ill-defined or messy problems (Vennix 1999). Almost since its inception, SD have involved the client in the model building process, because doing so helps the project leaders to capture the required knowledge, to increase the chance of implementation, and to enhance the clients' learning process. Group model-building has parallels to our multimethodology.

7.5 Ahus specific results; degree of implementation and future implications

7.5.1 Paper I

Which plausible, relevant, purposeful perspectives and subsequent root definitions can describe the real world activities in the ED, and can a process of obtaining these function as a precursor for an ED DES model? (Paper I)

Paper I describes the research performed in the ED initial to the development of the simulation model. In our research group, we focus on the importance of modelling a problem or an issue, not a system. We also acknowledge the importance of modelling the correct (i.e., real and most relevant) problem. These foci comprise the main background for the research described in Paper I. During a typical SSM application, the aim is to initiate and/or evaluate an organisational intervention. The aim of this paper however, is to describe the process of identifying and structuring problems and to describe the SSM process in the ED

and the following SSM-related results that are relevant to the upcoming simulation model. The aim of the SSM process was not in itself to optimise the unit. The paper does not focus on the processes beyond this initial phase of indentifying the important aspects that one should consider when building the simulation model. The title of the paper might therefore be a little misleading. It also does not discuss the reasons for initiating an optimisation project in the ED in the first place. These concepts and the link between Papers I, and IIa, and IIb are discussed in more detail in section 7.5.2 below.

Paper I describes 10 plausible, relevant, purposeful perspectives and subsequent root definitions that reflect the real world activities in the ED. In addition, two taboo perspectives are described. From these perspectives and root definitions, through conceptual models and comparison with the real world, we were able to highlight issues that were important to consider when developing the simulation model. In the simulation model described in papers IIa and b, all of these were considered, ensuring a simulation model with good face validity.

The results from the study were relevant not only for the simulation model, but also for the ED itself. The employees learned more about each other, and they were reminded of the importance of communicating with each other, patients and relatives. It was obvious that the organisation of the staff into the three divisions (nurses, physicians and surgeons) created problems in communication among the professions. This was also problematic with regard to the shared responsibility of the patients between doctors and nurses. In fact, shortly after this study was finished, the nurse division was abolished as described in the Introduction to Paper I.

It was interesting to observe that a commercialisation perspective was not mentioned at all during the workshop. The ED nurses and doctors seemed to perform their tasks not to earn money for themselves or for the hospital; rather, their inner motivation for doing their job was the Hippocratic Oath. Another interpretation resembles Karl Weick's thoughts. He argues that people make no

choice among opposing views; instead, the providers' daily working context totally dominates their perceptions and priorities. Hence when the ED staff tried to describe their workplace during our study, their descriptions might have been dominated by their patient-oriented daily view and not their monthly pay check, although we acknowledge that wages do play an important role in the lives of healthcare workers. A similar discussion between volunteer healthcare workers (for instance, Doctors Without Borders) would also have been informative for our purposes.

This paper focuses on how SSM can provide an understanding of the ED system by materialising all possible views and extant perspectives and thereby providing suggestions for improvements. This thinking is the central purpose of SSM. However, other ways to optimise organisations do exist. The patient flow through the ED can also be viewed as a *value chain*. A value chain is a chain of activities within an organisation that all add value to the product or service generated by the organisation. By disaggregating an organisation into these activities, a researcher can study each one in order to understand the behaviour and impact of each activity on the organisation's cost and value (Porter 1985). By viewing the patient flow through the ED as a value chain, one can find potential for optimisation within each of these disaggregated activities.

Stabell and Fjeldstad (1998) argue that the value chain appears well suited to describing and understanding a traditional manufacturing company, whereas it is less suitable to analysing activities in service industries. They introduce *value shop* and *value network* as better methods for analysing organisations that produce value by solving customers problems (value shop) or by linking customers (value network).

Lean is yet another way of analysing patient flow in order to optimise this flow. As the name suggests, the concept behind lean is to eliminate waste in the production flow (Wolmack and Jones 2003). In a healthcare setting, the

elimination of superfluous activity might involve studying activities, in for instance the ED, in order to eliminate unnecessary processes and resource use.

It could have been revealing to study the ED setting by applying these other processes-lenses, such as value chain, shop, or lean in order to see which approach is the most fruitful.

7.5.2 Link between Paper I and Paper IIa and b

The main reason for initiating an optimisation project in the ED in the first place and the link between all three papers is not discussed in detail in the papers themselves and therefore deserves an elaboration here.

The study in the ED at Åhus started with a vague feeling of inefficiency and a general concern regarding the upcoming patient volume increase in 2011. At the beginning of the study, the hospital's research director and the head of the medical division communicated these concerns to our research department. We therefore approached the management of the ED by suggesting a research study that would evaluate the perceived inefficiency. The aim of the study was firstly to understand and structure the problems in the unit and secondly to build a simulation model that would predict the unit's future resource needs. As mentioned earlier, our research philosophy is to make sure we understand the problem or issue to be studied before building a model, and secondly to build the model with a level of detail that is sufficient for answering the research questions. The SSM process was therefore initiated to structure the problems and develop an understanding of the main issues in the unit before trying to solve "the real problem". Secondly, the SSM process served as a tool for including stakeholders in the process from the beginning. Without the offsite, full-day workshop, we would have been unable to meet with all staff groups to discuss thoroughly the model building before beginning the project. The SSM process served as a precursor for the simulation model by identifying factors that should and should not be considered when building the simulation model. One of the issues with the

physical infrastructure was the location of the physicians' work station, which was not physically connected to the ED's entrance hall. This led to a challenge in communication between nurses and physicians, so the researchers found it necessary to model "call physician" as a separate activity in the simulation model. The physical separation also led to a general feeling of not having control over patient arrivals. Other communication issues were considered minor and not time consuming and were therefore not included in the model.

Other issues to consider in the model building were the different levels of staffing at different times of the day, different levels of skills for intern physicians and chief physicians, and waiting for available beds at the correct ward after ED examination. We also discovered that the main output measure would be LOS, because long patient waiting hours in the ED was both a hot topic in the media and a concern for both staff, management and patients. The long waits not only upset patients but also led to unnecessary occupation of treatment rooms. Staff utilisation was also a possible output measure from the model.

Together, the three papers describe the study in the ED. These papers do not describe in detail how long each process took. In total, the whole process with SSM and development of the first simulation model presented in Paper IIa took about six months, and the follow-up simulation model in Paper IIb took another three to four months.

Paper I concludes that this SSM process was a successful precursor for the upcoming simulation model. It might be argued that the simulation model could have been built satisfyingly without the formal SSM process and that we could have relied upon simply observation and conversations with staff and management. However, we do believe that the SSM process led to a deeper understanding of all the processes included in the simulation model. The process also encouraged the staff to develop a sense of model ownership which, in the end, would have led to a better acceptance of the potential implementation of

the simulation model results. Unfortunately, as described in the section below, the results could not be implemented directly.

7.5.3 Paper IIa and IIb

How can the ED prepare for a 40% patient volume increase?

- Does allocation of triage resources improve patient flow? (Paper IIa)**
- What will the main ED resource need be in 2011 after the patient volume increase? How many nurses, physicians, surgeons and treatment rooms are needed in 2011? (Paper IIb)**

After the initial SSM process described in Paper I, we were able to build a simulation model of the ED. With this model we evaluated the effect of the structural change implemented at the beginning of 2009, with the nurse triage replaced by physician triage (Paper IIa). Traditionally, nurse triage is the most common. However, physician triage has recently become a front-end intervention implemented to improve ED efficiency (Soremekun et al 2012, Russ et al 2010, Wiler et al 2010). In 2009, Ahus decided to implement this form of triage. This shift is evaluated in Paper IIa.

Paper IIa describes two models, one representing the nurse triage system and the other representing the physician triage system. The choice of building two separate models was one of convenience. We could have built one model running two different scenarios, but we found it easier to build two separate models, because the model-building processes in the software that we used was fairly easy and quick as long as the data and model coding were present. There were also some other process changes resulting from the physician triage system that made it easier to build two separate models. One extra activity that had to be included in the physician triage model was the greeting of patients upon arrival. After introducing physician triage, the nurses in the ED quickly realised one consequence of this change: the patients were not met at the door as they

previously had been by a triage nurse. This occurred because the physicians were a more limited resource than the nurses, and, unlike the nurses, the physicians were not present in the arrival hall at all times.

Another organisational change that needed to be modelled in the physician triage system was transporting patients to a room prior to the physician triage process. The reason for this lies in the complexity of the physician triage: it includes EKG examination undressing the patients, so it is not suitable to conduct in an ED entrance hall.

Several validation processes were performed for the two models to ensure consistency in the results and the elimination of errors. The same amount of model validation would have been necessary with one model running two scenarios.

The reason behind the change from nurse triage to physician triage was to decrease the average LOS for ED patients because a nurse resource would be released for nurse examination of patients. What our model showed was that the LOS would not decrease with this change. This is in accordance with the results of Han et al. (2010), who show that introducing physician triage does not significantly influence the LOS of admitted patients in the ED. On the other hand, other studies do demonstrate a decrease in LOS and/or a decrease in time to physician examination when placing a physician in triage (Wiler et al 2010), either without additional medical or nursing staff (Rogers et al 2003, Subash et al 2004 and Travers and Lee 2006) or with extra staff (Choi et al 2006, Holroyd et al 2007, Patrovi et al 2001, Russ et al 2010, Soremekun et al 2012). One study added extra staff to the triage only when staffing levels permitted (Terris et al 2004). In studies where additional staffing was required, the results have to be viewed in light of increased costs (Patrovi et al 2001, Soremekun et al 2012, Soremekun et al 2011). In our study the triage physician was allocated from the pool of physicians who were dedicated for patient examination. The main reason for why our analysis shows no LOS decrease with changing from nurse to physician triage

can be seen in paper IIb where we demonstrate that the physicians are the main bottle neck in the ED. Another difference between the studies referenced above and the ED at Ahus is in the role of the ED. As described in section 4.1.1, ED patients at the hospital are more severely ill than the average patient in the outpatient emergency ward centre, and ED patients would therefore normally need hospitalisation. Hospitals in other countries tend to discharge patients after ED treatment more often than Norwegian hospitals do. One effect of placing a physician in triage is to discharge patients quicker. This effect, however, does not apply to our setting, since nearly all ED patients require hospitalisation.

Our models predict an average LOS of 297 minutes in the nurse triage model and 288 in the physician triage model. This is slightly above the estimates reported by Fee et al (2012). Based on the 2008 National Hospital Ambulatory Medical Care Survey, which is a national probability sample of 396 American hospitals, they report a median ED LOS of 270-280 minutes for admitted patients.

The only significant difference between physician triage and the nurse triage system described in Paper IIa was that patients in a physician triage system are seen briefly by a physician earlier. However, it does not significantly change the waiting time for physician examination. We also observed that the waiting time for nurse examination might decrease. In the nurse triage model, this was 55 minutes, in comparison to 33 minutes in the physician triage model. Now I'd like to remind the reader that it was the *intended* system that was modelled in this study. What was observed in real life after introducing physician triage in peak hours was that the nurses would still dedicate a nurse for triage tasks, also in peak hours! This resulted in double triage and the loss of one resource instead of freeing a resource for nurse examinations, which was one of the main reasons for introducing physician triage. The reason for this double triage is unclear, but it can be assumed that the nurses, who are physically in the ED at all times, see the patients as they enter the door, in comparison to the physicians, who sit in a room farther down the corridor and see patient arrivals only on a computer. This

observation can also be discussed in relation to the results from the SSM process: that sharing responsibility for patients between nurses and doctors is difficult, as is communication across professions.

The change from physician to nurse triage happened before we entered the ED, and hence also before our SSM workshop. If an SSM process had been carried out before this change was implemented, the ED management could have had a better understanding for why and how this might not work.

The differences in time spent on the different activities in the two simulation models were relatively small and insignificant. In addition, the introduction of physician triage did not free a nurse resource in real life. However, there was another aim to this structural change, namely to increase the quality of the service in that the physician would be involved with the patient at an earlier point in time. This might be comforting for patients even though the main physician examination would not happen significantly earlier. Even so, the system with physician triage was abandoned within a year of the implemented change due to reasons described above, but also due to an increasing awareness that the physicians are the actual bottleneck in the ED, which also is the main conclusion of Paper IIb.

Paper IIb evaluates the patient volume increase in 2011 and the resulting increase in demand on ED resources. We built the simulation model in Paper IIb on the basis of the physician triage model in Paper IIa. However, we did need to make some changes after observing the system a few months later. As described above, the theory did not fit the practice, because the nurses still dedicated a nurse for triage tasks during physician triage hours. Therefore, we systemised a nurse “mini-triage” (“Nurse: BP, temp, pulse”) in the updated model in Paper IIb, and the original nurse examination activity then began after the triage process. The activity of “greeting patient” is no longer included in the model in Paper IIb, because it was replaced by the “mini-triage” activity.

First of all, the baseline results (based on the whole year of 2009) show a significant reduction in LOS compared to what is reported in Paper IIa (which is based on a six-week timeframe in the beginning of 2009). This is consistent with what was observed in practice. The results from the scenario analyses indicate that the regular physicians' capacity is the most important factor. We also observed that increasing the bed capacity is not necessary after increasing staff capacity. Paper IIb concludes that increasing the nurse capacity from an average of eight to nine nurses and increasing the physicians and surgeons from an average of eight to 12 would meet the needs from the increased patient volume in 2011 without compromising the waiting time in the ED. The strategy of one additional nurse does not influence the patient flow, but it does reduce the nurse utilisation rate by three percentage points. During a model run, the relationship between the utilisation rate and the number of staff was influenced only by the average treatment time and the number of patients. Reducing the utilisation rate to the reference value of 31% at baseline in Table 3 in Paper IIb by increasing the number of nurses is therefore a trivial calculation, because the relationship is linear. Such a calculation demonstrates a need for 11.6 nurses to reduce the utilisation rate to 31%.

Out of curiosity, we ran four more scenarios of possible resource increases. Scenarios K, L, and M logically follow scenario J, whereas scenario N represents what was actually implemented in 2011. The results of these scenarios appear in Table 4.

	Baseline	J	K	L	M	N
Beds	17	17	17	17	17	18
Nurses	8	9	10	11	12	14
Physicians	8	12	12	12	12	10
Triage nurses	2	2	2	2	2	2
Triage physicians	2	2	2	2	2	2
Time to complete activities:						
Time from arrival to nurse triage	32	44	43	45	43	89
Time from arrival to physician triage	22	38	35	37	37	45
Time from arrival to physician exam	188	177	177	177	175	232
Total time in ED	238	232	231	232	230	283
Utilisation:						
Regular nurse	31%	40%	36%	34%	31%	27%
Regular physician	56%	58%	58%	58%	58%	65%
Triage nurse	45%	46%	46%	47%	46%	47%
Triage physician	47%	47%	47%	47%	47%	47%
Bed area	45%	56%	57%	57%	56%	64%

Table 4: Additional results: patient waiting time and staff utilisation in three additional scenarios of resource increase following an expected 45% increase in patient volume. Please also refer to Table 2 in section 6.3 for Scenario A-I.

The data in this table support the conclusion that additional nurses do not influence the patient flow, but the addition does reduce the nurse utilisation rate in a linear fashion. If both patient waiting times and staff utilisation were to remain unchanged from baseline, then there would be a need for increasing the nurse capacity from an average of eight to 12 nurses and increasing the physicians and surgeons from eight to 12. Table 3 in Paper IIb (and Tables 2 and 4 here) presents both patient waiting times and staff utilisation. The utilisation rates for nurses and physicians are, however, not directly comparable. The physicians and surgeons have other obligations outside the ED for about 50% of their work time, which is handled in the model. The nurses have tasks which are ED related, but which are not directly related to patients, and these were not included in the model. This omission might be a limitation to the model and might make the interpretation of the results in the tables more difficult. We could have handled the incongruity better by normalising the utilisation rate or spending

more time quantifying and modelling the not directly patient related activities of both nurses and physicians.

Unfortunately, the results from our study could not be implemented directly. The restructuring of the hospital districts in Oslo and its suburbs gave Ahus a limited number of additional authorised medical doctor positions⁴. These had to be distributed throughout the hospital, and the management decided that increasing the physician capacity in the ED by 50%, as our study suggested, was not feasible. Since there were fewer restrictions on the number of nurses, it was decided instead to increase the nursing staff to an average of 14 regular nurses. The hospital also rebuilt the area to include an extra treatment room and an observation area for patients waiting for radiological examination or for transfer to a ward. Physician capacity was increased by one to two, depending on the time of day.

Out of curiosity, we also decided to run this implemented scenario in our model, unfortunately, we did so after the submission of this paper. Nevertheless, we show the results of scenario N in Table 4. This scenario projected that the ED would be overcrowded and that the LOS would increase significantly within a short amount of time. About six months into 2011, we were proven right, and the management approached us to ask for a new evaluation of the physician resources in the ED. The results of these new analyses have not yet been published, but they support the conclusions in Paper IIb that the physicians are, indeed, the bottleneck.

Our ED studies show the importance of understanding the system before trying to implement changes. **An intervention will not be successful if the willingness to change is not present** among the staff on the floor, which was the main problem that we encountered during the physician triage intervention. This

⁴ Since Norwegian hospitals are publicly funded, every hospital in Norway has a limited number of authorised medical doctor positions due to a national policy for an even distribution of medical doctors throughout the country.

is in line with the literature as described in Section 2. Our studies also provide strong evidence for the value of using simulation models for estimating the consequences of changes before implementing them.

7.5.4 Paper III

What is the best allocation of beds among wards to achieve the fewest number of crowding patient days for the hospital in total? (Paper III)

The bed allocation study presented in Paper III was first initiated as a project by the CEO of the hospital in the spring of 2011. The aim was to estimate the best possible allocation of beds among the different wards of the hospital, in order to keep the use of crowding beds at a minimum. A project group was established consisting of the directors from each department of the hospital, among others.

A couple of weeks into the project I was contacted by the project leader to support the group's decisions with a bed allocation simulation model. Since this was already an ongoing project with a tight time schedule, it was not possible to do an SSM process in advance. However, since we did not want to begin the modelling before a consensus was reached on the principles behind the simulation model, we did spend a lot of time discussing this with the project group. Even so, when the results from the model were presented to the project group, these were not very well received. A heated and many weeks' long discussion followed about hidden agendas and whether poorly run wards should be awarded with additional beds while well run wards that were able to decrease LOS should be punished for this by having to give up beds.

The project had failed in understanding the difficulty (impossibility) of giving up beds. The question that was asked should not have been how we could reallocate the beds among the wards. The project instead should have asked for other possible solutions to the problem, or asked what the real problem actually was. There were obviously many cultural issues that were not taken into account

in this process. The personalities of both project groups, the attitudes at each ward, the local politics, and the complex power relationships affected the implementation. What seemed on paper to be a nice tidy mathematical problem with a neat solution was, in reality, far from it. An SSM process would have been beneficial for this purpose.

The paper describes the problem, the model, the algorithms, and the results in detail. However, the implementation issues are not discussed in detail. The lessons learned from this modelling experience were clear. In order to ensure a well functioning implementation of the results from a model it is important to understand the view of the different stakeholders. The whole bed allocation project can be argued to be an error of the third kind, as discussed in section 7.2.1: Technically elegant simulation models are not useful if they do not address the real problem.

Even though the bed allocation group and the simulation model did not solve the real culture-related problem, the model did provide objective solutions to the issue of allocating beds between wards, and it did serve as a decision support tool for the management. The study was also a formal proof of a concern that the staff on the floor had expressed: an unreasonable distribution of beds among wards. Some changes were made based upon the results from the model. Among other measures, an additional Gastro surgery ward was established in the area of the patient hotel, and Orthopaedics received some beds in the Children's Department. The project was also a starting point for the establishment of a palliative ward.

7.5.5 Paper IV

How can the CSU prepare for the patient volume increase? Where is the bottleneck? (Paper IV)

The main aim of Paper IV is to describe the combination of SSM and DES into a multimethodology while describing the case application at the CSU at Åhus. The development of the multimethodology has already been described and discussed thoroughly. This section will discuss the CSU-specific results of that study.

The CSU study started with the head of the department approaching me and asking: Can you build a simulation model and find out where our bottleneck is? Contrary to management's initial expectations, the overall results from the simulation model showed that there were no critical bottlenecks in the system. We were able to show that it is the sum of potential small delays in every activity performed by several actors before, during and after each surgical procedure that leads to delays and non-productive use of time. Our results were based on running three different scenarios of one OT, each model run with a length of one day with 10,000 repetitions. With an average of three procedures per day per OT this gave us a dataset of 30,000 surgical procedures per scenario.

Our proposal to the management included suggestions for improvements with direct and indirect impact on surgical activity. As a result of this, the management decided to convert the two specialised OTs so they could be utilised for regular procedures, too. The management has also increased the elective operating hours of some OTs, and has included more flexibility in the nurses' working schedules. In addition, the different professions are currently considering ways to be more synchronised in their work schedules and regular meetings. The potential for decreasing the number of low activity weeks is still unclear.

Through the changes described above together with increased staffing, the CSU has been able to meet the increase in activity in 2011, although a large

proportion of the elective program had to be postponed the first six months of 2011. Our suggestion for improvement with indirect impact on surgical activity included an enhancement of non-technical skills like team behaviour and team leadership, along with communication and cooperation. The positive effect of non-technical skills on the overall performance of a surgical team has been demonstrated in the literature (Flin and Mitchell 2009). Improved teamwork in surgical theatres is associated with increased patient safety and fewer complications, increased efficiency and better work environment (Davenport et al. 2007; Mazzocco et al. 2009; Neily et al. 2010).

During the second half of 2011, the management of the CSU, in cooperation with us, initiated a new project with focus on non-technical skills. In this project a large group, consisting of researchers and representatives from the CSU, has been working towards creating new CSU guidelines that facilitate better communication, cooperation and team behaviour within and among OTs. The pilot phase of this study indicates that improved team behaviour is increasing surgical efficiency.

7.6 General discussion

Our research contributes to the literature where methodologies from soft and hard paradigms are combined. We did not only use SSM and DES within the same intervention. We have also shown how we combined these two methods into one multimethodology, and we have demonstrated the success of applying the results in an actual hospital setting. Literature shows that combining SSM and DES can be advantageous (see Section 2.3 for an overview of the literature), and our results confirm this.

Experiences in relation to the literature

Section 2.3 describes the general management literature on combining methods. These case studies all demonstrate the success of combining soft and hard

techniques as well as how this combination might help researchers to enhance their understanding of the issue at hand and to produce results of greater comprehensiveness. Combination of methods from different paradigms can inspire us to define and analyse problems more efficiently in organisational research (Jick 1979, Luyt 2012, Petros 2012, Robinson and Mendelson 2012, Rocheleau 1995, Teye 2012, Yu 2012 and Yu et al 2006). In section 2.3.1, we narrow down the literature review to the papers that address the combination of SSM with DES in the healthcare industry. SSM serves to include the stakeholders in the project from the beginning, which gives them a sense of model ownership (Mingers and Gill 1997) and a greater understanding that in turn encourages the acceptability of the simulation model (Lehaney and Paul 1996; Lehaney et al. 1999; Lehaney and Paul 1994). This was very obvious in the CSU study. It was also the case in the ED study, although the initial simulation model results were not implemented. The reason for this was both the hospital's limited number of authorised doctor positions and the fact that the ED management was changed during the study period. What we could have done in the ED was to spend more time including the new management in the study.

The main difference between the ED and the CSU studies was the attitude of the stakeholders: while the ED was there for the researchers' sake, the researchers were there for the CSU's sake. The main reason for this behaviour was because the ED study was initiated by the researchers while the CSU management initiated the CSU study. These differences can be compared, but are not equal to, top-down versus bottom-up management. In top-down approaches, decisions or initiatives are made by an executive, a decision maker, or another person or body, and it can be difficult for lower levels to accept them. A bottom-up approach is one where initiatives come from the lower levels, from the people who face the everyday challenges (Robbins 1997). Even though the challenges these two units faced were the same (the upcoming patient volume increase), the initiative for a research study to explore possible solutions to this challenge came

from different angles and may have contributed to the degree of implementation success in the two studies.

For the bed allocation study, the participants were included in the modelling process from the beginning. They were also encouraged to study the details of the model with the researchers. However, we did not, unfortunately, raise important issues early enough to encourage the acceptability of the final simulation model and its results. Lehaney and Hlupic (1995) argue that this risk might be reduced when including SSM in the process. Kotiadis and Mingers (2006) also demonstrate that by adding findings from an SSM process into the simulation models they were able to build models that answered questions that were more important to the stakeholders. It is therefore unfortunate that we were not able to carry out an SSM process in relation to this project. However, this supports our conclusion that a combination of soft and hard approaches might yield synergies that would not be obtained with use of either method alone.

In a recent review, Günal and Pidd (2010) describe how the literature is full of similar case study papers on similar problems within health care simulation. There are too many examples of what can be done rather than something that practitioners and researchers might learn from. They state that it would be a step forward in the health care simulation literature if authors of unit and facility specific models describe their approaches with enough detail to permit others to reuse their approaches. They conclude the review with: *“As DES approaches have been used in health care for over 30 years, it may be time to take a serious look at the issue of model implementation and use”* (Güenal and Pidd 2010, p. 49). Implementation issues are discussed in the next section. In our bed allocation paper (Paper III), we have tried to follow one of Güenal and Pidds recommendations by developing and describing a generic simulation model for bed allocation and supplementing this with generic optimisation algorithms. In addition, we prove that this generic approach works in our hospital environment.

Through the studies presented in this thesis, we have had a focus on model implementation and use, encouraged by Günal and Pidd. This was possible through the combined use of soft and hard research approaches.

Implementation barriers

Many health care simulation projects are not successfully implemented (Damschroder et al. 2009; Wilson 1981). Barriers to implementation are many; Harper and Pitt (2004) discuss a number of these. First of all, the size, complexity, diversity and constant change of health care services present a challenge for modellers. This was a challenge especially in the ED study in that parts of the system were changed many times during our study period. Another barrier to implementation is the health care stakeholders' unfamiliarity with OR approaches. This requires a constant dialogue and ensuring that the most important and relevant issues are addressed. We spent a lot of time building up trust and showing the stakeholders that "we knew what we were doing". This was both important and beneficial for implementation success. Conflicting political objectives between management and medical personnel are also barriers to implementation. With simulation modelling it is possible to reduce this political tension by objectively quantifying the impact of change. However, even with an objective and righteous bed distribution model, the political debate between the stakeholders was obviously inevitable in the bed distribution study. Lack of health care data quality is another challenge for successful implementation, as discussed by Harper and Pitt (2004). Our experience with this is discussed in Section 4.2.

Smith-Daniels et al (1988) also discuss barriers to implementations in health care. They conclude that research efforts often fail during the implementation phases because it is impossible to balance the conflicting objectives of the various health care professionals. This is in line with our experiences in the bed allocation project.

In the ED, the main implementation barriers were the change in management and the limitations in authorised medical doctor positions. During the physician triage experiment, the main implementation barrier was the unwillingness to change. For the bed allocation study, we ran into barriers, because we did not consider the hospital's political and cultural tensions. Personalities, local politics, and complex power relationships also affected the implementation. The bed allocation study demonstrated an error of the third kind; when not addressing the real problem the results cannot be expected to be implemented.

Many of the implementation barriers discussed above apply to other fields in addition to healthcare. Some of the organisational-level experiences reported in this thesis might therefore be generalisable to other fields, although healthcare comes with numerous special issues that do not apply to other fields.

Key statements

Throughout this discussion, some key statements have been highlighted in boldface. These statements are grounded in the literature, and Harper and Pitt (2004) and Brailsford (2005) addresses some of them. In our research, the following bullet points were experienced as the most important for successful implementation of interventions:

- Simulation models are not useful if they do not address the real problem (Mitroff and Featheringham 1974)
- It is important to understand the different stakeholders' perspectives and their subsequent purposeful activities (Checkland 2000)
- It is necessary to anchor the project well among the stakeholders and involve them closely (Harper and Pitt 2004; Lehaney and Paul 1996; Lehaney et al. 1999; Lehaney and Paul 1994; Wilson 1981)

- Changes that are both desirable and culturally feasible should be discussed with stakeholders; agreement should be reached on possible actions to improve the situation (Checkland 2000)
- Future consequences of possible changes should be predicted before implementing them (Banks et al. 2010; Pidd 2004; Robinson 2004)
- An intervention will never be successful if the willingness to change is not present among the stakeholders influenced by the change

The last bullet point can be divided into two steps. First, the intervention needs to be practically implemented. Second, it is necessary to ensure that the stakeholders comply with the implemented change.

Naturally, these are not the only criteria for a successful implementation of changes. It also requires that there actually exist desirable and feasible solutions to the problem situation being studied. Also, not all problem situations can be solved using OR techniques. However, in our research, we experienced that these statements were the most important criteria for success. In Table 5, we show how they were fulfilled in the three studies in this thesis.

Success criteria	ED study	Bed allocation study	CSU study
a) Understand the real problem	+	-	+
b) Understand the stakeholders' perspectives and purposeful activities	+	-	+
c) Anchor the intervention among all stakeholders from the beginning and involve them closely	+	+	+
d) Agree on feasible and desirable changes	-	-	+
e) Explore possible quantitative consequences of the intervention before implementation	+	+	+
f) Implement the solution successfully	-	-	+
g) Ensure compliance with the implemented change	-	-	+

Table 5: Criteria for a successful intervention, and how this was fulfilled in our studies

In the ED study we used SSM and DES successively. We used SSM as a precursor for the development of a simulation model. Thereafter, we developed the

simulation model that showed that replacing nurse triage with that of a physician would not decrease LOS in the ED. With the simulation model we also demonstrated that physicians were the bottleneck in the ED. What we did not do was to bring these results back to the stakeholders for a thorough discussion of feasible and desirable changes. This was partly due to the restructuring of the management. Fulfilled success criteria, according to Table 5, were: a) understanding the real problem, b) understanding stakeholders' purposeful activities, c) anchoring (partly fulfilled) and e) exploring possible consequences. Criteria d) agreeing on feasible and desirable changes, f) successful practical implementation and g) ensuring compliance with the implemented change were not fulfilled in this study.

In the bed allocation study described in Paper III, we were not able to use SSM due to the timing of the already ongoing project. A simulation model was developed in close cooperation with the stakeholders. The fundamentals for the model were well anchored among them, but according to the success criteria in Table 5, a) understanding the real problem, b) understanding the stakeholders' purposeful activities and d) agreeing on feasible and desirable changes were not fulfilled. Only c) anchoring the intervention among stakeholders and e) exploring possible consequences of the intervention were fulfilled, which led to an unsuccessful implementation of the results (f and g).

In the CSU study, Paper IV, SSM and DES were used in combination and all criteria for a successful intervention were fulfilled. This supports our conclusion that when soft and hard paradigm methodologies are used in a combined way, an intervention is more likely to be successful.

A summary on how the success criteria can be achieved through SSM and DES respectively is shown in Table 6. Only by combining the two methods is it possible to fulfil all success criteria.

Success criteria	Can be achieved by SSM?	Can be achieved by DES?
a) Understand the real problem	Yes	No
b) Understand the stakeholders' perspectives and purposeful activities	Yes, but requires a)	No
c) Anchor the intervention among all stakeholders from the beginning and involve them closely	Yes	Yes
d) Agree on feasible and desirable changes	Yes	No
e) Explore possible quantitative consequences of the intervention before implementation	No	Yes
f) Implement the solution successfully	Yes, but requires a), b) and c)	Yes
g) Ensure compliance with the implemented change	Yes, but requires a), b), c), d), e) and f)	Yes, but requires a), b), c), d), e) and f)

Table 6: Criteria for a successful intervention and how it can be achieved through SSM and DES respectively

Limitations

Tables 5 and 6 above describe the success criteria demonstrated in this thesis and provide the basis for the conclusion that an intervention may be more successful by using SSM and DES in combination, as in the CSU study in Paper IV. However, there might also be alternative explanations for the success reported in Paper IV and for the failures of the implementation in the other papers. For example, the bed allocation study reported in Paper III deals with the entire hospital, which includes numerous stakeholders with conflicting goals, so that implementation is more difficult to execute than the implementation in the CSU study from Paper IV, which deals only with one hospital unit. The bed allocation study might not have been successful even with an SSM process in addition to the simulation model. An SSM process with stakeholders from all hospital units might have been difficult to arrange, as well.

Another explanation for the success of Paper IV compared to the others might be related to hospital political issues. The bed allocation study was initiated by the hospital management, whose agenda might have been to demonstrate that the total number of beds at the hospital was sufficient. The CSU study was

initiated by the CSU management, whose agenda was to understand genuinely their own situation and to find solutions to their challenges. Finally, the ED study was initiated by the researchers with their own political research agenda.

It is also tempting to analyse the success of the different studies based on the interpersonal relationships between researchers and stakeholders. Perhaps the CSU staff and management believed in the researchers' ideas more than the bed distribution group and the ED staff did.

A common limitation to all of the studies presented in this thesis is that they were not planned in advance. This is discussed in section 7.1 in the light of an action research design. The research questions arose, and the researchers' experience grew, as the research progressed.

The overall research question of this thesis is whether a combined use of SSM and DES can be more useful than the additive effect of using each method successively within the same intervention. This is a challenging research question. Even though there might be alternative explanations for success than the ones we offer in Tables 5 and 6, we still believe the research discussed in this thesis supports our hypothesis. However, the generalisability is limited with only four modelling experiences in one hospital. Generalising findings beyond the local situation is a well known limitation of action research, although action research conducted in one setting to help members of that setting can produce knowledge that is generalisable to other settings (Reason and Bradbury 2006).

8. Conclusion and future perspectives

In soft paradigm research like SSM, the aim is to understand the different actors' enquiry into the real world and their behaviour towards the system, and thereby bring about feasible and desirable changes. In hard paradigm research, like simulation, the aim is to explore possible consequences of interventions before

implementing them. Valuable changes can evolve from applying each methodology alone. The studies discussed in this thesis indicate that the use of methodologies from both paradigms in combination will be not only more valuable than the use of either method alone, but also more valuable than successive use of the two methodologies within the same intervention.

Tables 5 and 6 show seven criteria for a successful intervention as experienced through the research in this thesis and how these can be achieved through SSM and DES respectively. In Table 5 we show how our three projects fulfil each of these criteria. In the CSU study, SSM and DES were used in combination and all of our criteria for a successful intervention were thereby fulfilled. Given its limitations, this thesis indicates that when soft and hard paradigm methodologies are used in a combined way, an intervention is more likely to be successful.

The thesis also demonstrates that there are many barriers to successful implementation of health care interventions. Interventions in a hospital are difficult and expensive, and whether or not the intervention will be a success is most of the time not known. Very often the ones who implement the intervention do not know enough about the stakeholders' views on the system and their purposeful actions. This is an important barrier to the intervention. By following the multimethodology we have developed and described in this thesis, the probability for fulfilling all success criteria described in Table 5 increases, and this again increases the probability for successful implementations of desirable and feasible interventions, to which the stakeholders would comply.

References

- Ackoff, R.L. 1979. The Future of Operational Research is Past. *The Journal of the Operational Research Society*, 30, (2) 93-104
- Ahus 2012, *Internal report: Central Surgery Unit Ahus*.
- Ahus 2010 DIPS, Ahus' electronic patient database.
- Andrulis, D.P., Kellermann, A., Hintz, E.A., Hackman, B.B., & Weslowski, V.B. 1991. Emergency departments and crowding in United States teaching hospitals. *Annals of Emergency Medicine*, 20, (9) 980-986 available from: PM:1877784
- Banks, J., Carson II, J.S., Nelson, B.L., & Nicol, D.M. 2010. *Discrete-Event System Simulation* New Jersey.
- Brailsford, S., Harper, P.R., Patel, B., & Pitt, M.A. 2009. An analysis of the academic literature on simulation and modelling in health care. *Journal of Simulation*, 3, 130-140
- Brailsford, S. 2005. Overcoming the barriers to implementation of operations research simulation models in healthcare. *Clinical and Investigative Medicine*, 28, (6) 312-315 available from: ISI:000237555500003
- Brailsford, S. & Hilton, N. A. 2001. Comparison of Discrete Event Simulation and System Dynamics for Modelling Healthcare Systems, *In Planning for the Future: Health Service Quality and Emergency Accessibility, Operational Research Applied to Health Services (ORAHS)*, ed: J. Riley, j., Glasgow Caledonian University.
- Brailsford, S. & Schmidt, B. 2003. Towards incorporating human behaviour in models of health care systems: An approach using discrete event simulation. *European Journal of Operational Research*, 150, (1) 19-31 available from: ISI:000183680700003
- Brailsford, S. & Vissers, J. 2011. OR in healthcare: A European perspective. *European Journal of Operational Research*, 212, (2) 223-234 available from: ISI:000290084300001
- Brailsford, S.C., Harper, P.R., & Sykes, J. 2012. Incorporating human behaviour in simulation models of screening for breast cancer. *European Journal of Operational Research*, 219, (3) 491-507 available from: ISI:000302199300002
- Checkland, P. 2000. Soft systems methodology: A thirty year retrospective. *Systems Research and Behavioral Science*, 17, S11-S58 available from: ISI:000165711500003
- Checkland, P. & Scholes, J. 1990. *Soft Systems Methodology in Action* Chichester, Wiley.
- Choi, Y.F., Wong, T.W. & Lau, C.C. 2006. Triage rapid initial assessment by doctor (TRIAD) improves waiting time and processing time of the emergency department. *Emergency Medical Journal*, 23, 262-265

Cowan, R.M. & Trzeciak, S. 2005. Clinical review: Emergency department overcrowding and the potential impact on the critically ill. *Crit Care*, 9, (3) 291-295 available from: PM:15987383

Coyle, R.G. 1996. *System Dynamics Modelling: a practical approach*. London: Chapman & Hall

Damschroder, L.J., Aron, D.C., Keith, R.E., Kirsh, S.R., Alexander, J.A., & Lowery, J.C. 2009. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implementation Science*, 4, available from: ISI:000269819300001

Davenport, D.L., Henderson, W.G., Mosca, C.L., Khuri, S.F., & Mentzer, R.M. 2007. Risk-adjusted morbidity in teaching hospitals correlates with reported levels of communication and collaboration on surgical teams but not with scale measures of teamwork climate, safety climate, or working conditions. *Journal of the American College of Surgeons*, 205, (6) 778-784 available from: ISI:000251439800008

Derlet, R.W. & Richards, J.R. 2002. Emergency department overcrowding in Florida, New York, and Texas. *Southern Medical Journal*, 95, (8) 846-849 available from: PM:12190219

Eden, C. & Ackermann, F. 2006. Where next for problem structuring methods. *Journal of the Operational Research Society*, 57, (7) 766-768 available from: ISI:000238385600003

Fee, C., Burstin H., Maselli, J.H. & Hsia, R.Y. 2012. Association of Emergency Department Length of Stay With Safety-Net Status. *The Journal of the American Medical Association*, 307, (5) 476-482

Fildes, R. & Ranyard, J.C. 1997. Success and survival of operational research groups - A review. *Journal of the Operational Research Society*, 48, (4) 336-360 available from: ISI:A1997WU19900002

Flin, R. & Mitchell, L. 2009. *Safer Surgery. Analysing Behaviour in the Operating Theatre* Ashgate, Surrey.

Gilbert, N. & Troitzsch, K.G. 2005. *Simulation for the Social Scientist* Open University Press, Berkshire.

Günal, M.M. & Pidd, M. 2010. Discrete event simulation for performance modeling in health care: a review of the literature. *Journal of Simulation*, 4, 42-51

Hagen, T. P. & Kaarbøe, O. M. 2012, *The Norwegian Hospital reform of 2002: Central government takes over ownership of public hospitals*, Working paper 2004:1, Health Organization Research Norway, University of Oslo.

Han, J.H., France, D.J., Levin, S.R., Jones, I.D., Storrow, A.B., & Aronsky, D. 2010. The Effect of Physician Triage on Emergency Department Length of Stay. *Journal of Emergency Medicine*, 39, (2) 227-232 available from: ISI:000281290000020

Harper, P.R. & Pitt, M.A. 2004. On the challenges of healthcare modelling and a proposed project life cycle for successful implementation. *Journal of the Operational Research Society*, 55, (6) 657-661 available from: ISI:000222017500011

Hindle, G.A. & Franco, L.A. 2009. Combining problem structuring methods to conduct applied research: a mixed methods approach to studying fitness-to-drive in the UK. *Journal of the Operational Research Society*, 60, (12) 1637-1648 available from: ISI:000270954100003

Hindle, T., Checkland, P., Mumford, M., & Worthington, D. 1995. Developing a Methodology for Multidisciplinary Action Research: A Case Study. *Journal of the Operational Research Society*, 46, (4) 453-464

Holm, L. B. & Barra, M. 2012. The consequences of how Subject Matter Experts are interpreted and modelled, demonstrated by an Emergency Department DES Model comparing triangular and beta distributions, *Proceedings of the 2011 Winter Simulation Conference*, eds: Jain, S., Creasey, R. R., Himmelspach, J., White, K. P. and Fu, M.

Holm LB, Barra M and Dahl FA (2012). Towards a Multimethodology in Health Care - Synergies between Soft Systems Methodology and Discrete Event Simulation. *Health Systems*, available online 19 October 2012, doi:10.1057/hs.2012.21

Holm LB and Dahl FA (2011). Using Soft Systems Methodology as a precursor for an emergency department simulation model. *OR Insight* 24(3): 168-189.

Holm, L. B. & Dahl, F. A. 2010. Simulating the influence of a 45% increase in patient volume on the Emergency Department of Akershus University Hospital, *Proceedings of the 2010 Winter Simulation Conference*, eds: Johansson, B., Jain, S., Montoya-Torres, J., Hagan, J. and Yücesan, E., pp. 2455-2461.

Holm, L. B. & Dahl, F. A. 2009. Simulating the Effect of Physician Triage in the Emergency Department of Akershus University Hospital, *Proceedings of the 2009 Winter Simulation Conference*, eds: Rossetti, M. D., Hill, R. R., Johansson, B., Dunkin, A. and Ingalls, R. G.

Holm LB, Lurås H and Dahl FA (2012). A simulation model of hospital bed utilisation. With application to a 40% increase in patient volume in a Norwegian general hospital. *International Journal of Medical Informatics*, Available online 13 June 2012, <http://dx.doi.org/10.1016/j.ijmedinf.2012.05.006>

Holroyd, B.R., Bullard, M.J., Latoszek, K., Gordon, D., Allen, S., Tam, S., Blitz, S & Yoon, P. 2007. Impact of a triage liaison physician on emergency department overcrowding and throughput: a randomized controlled trial. *Academic Emergency Medicine*, 14:702-708.

Holter, I. M. & Schwartz-Barcott, D. 1993. Action research: what is it? How has it been used and how can it be used in nursing? *Journal of Advanced Nursing*, 18, 298-304

Howick, S. & Ackermann, F. 2011. Mixing OR methods in practice: Past, present and future directions. *European Journal of Operational Research* 215, 503-511

INFORMS. *Executive guide to operations research*. 14-3-2012. Online Source: http://www.scienceofbetter.org/or_executive_guide.pdf

Jick, T. D. 1979. Mixing Qualitative and Quantitative Methods: Triangulation in Action. *Administrative Science Quarterly*, 24, (4) 602-611

- Johnson, M., Myers, S., Wineholt, J., Pollack, M., & Kusmiesz, A.L. 2009. Patients Who Leave the Emergency Department Without Being Seen. *Journal of Emergency Nursing*, 35, (2) 105-108
- Kennedy, M., MacBean, C., Brand, C., Sundararajan, V., & McD Taylor, D. 2008. Review article: Leaving the emergency department without being seen. *Emergency Medicine Australasia*, 20, (4) 306-313
- Koch, T. & Kralik, D. 2006. *Participatory Action Research in Health Care*. Backwell Publishing, Oxford
- Kotiadis, K. 2006. Extracting a conceptual model for a complex integrated system in health care. *Proceedings of the 2006 OR Society Simulation Workshop*, eds. Robinson, S., Taylor, S., Brailsford, S. and Garnett, J.
- Kotiadis, K. 2007. Using soft systems methodology to determine the simulation study objectives. *Journal of Simulation*, 1, 215-222
- Kotiadis, K. & Mingers, J. 2006. Combining PSMs with hard OR methods: the philosophical and practical challenges. *Journal of the Operational Research Society*, 57, (7) 856-867 available from: ISI:000238385600014
- Kreher, H. 1994. Some Recurring Themes in Using Soft Systems Methodology. *Journal of the Operational Research Society*, 45, (11) 1293-1303 available from: ISI:A1994PQ00300007
- Law, A.M. 2007. *Simulation, Modeling and Analysis* New York, McGraw-Hill.
- Law, A. M. 2009. How to build valid and credible simulation models, *Proceedings of the 2009 Winter Simulation Conference*, eds: Rossetti, M. D., Hill, R. R., Johansson, B., Dunkin, A. and Ingalls, R. G., pp. 24-33.
- Ledington, P. & Donaldson, J. 1997. Soft OR and management practice: A study of the adoption and use of soft systems methodology. *Journal of the Operational Research Society*, 48, (3) 229-240 available from: ISI:A1997WK57100001
- Lehaney, B. & Clarke, S. A. 1997. Soft systems methodology (and simulation) for mixed mode modelling, *Operational Research Keynote Papers*, eds: O'Brian, F. and Orman, A., Birmingham, UK: Operational Research Society, pp. 16-33.
- Lehaney, B. & Hlupic, V. 1995. Simulation modelling for resource allocation and planning in the health sector. *Journal of the Royal Society of Health*, 115, (6) 382-385
- Lehaney, B. & Paul, R. J. 1996. The Use of Soft Systems Methodology in the Development of a Simulation of Out-patient Services at Watford General Hospital. *Journal of the Operational Research Society* 47[7], 864-870. 1996.
- Lehaney, B., Clarke, S.A., & Paul, R.J. 1999. A case of an intervention in an outpatients department. *Journal of the Operational Research Society*, 50, (9) 877-891 available from: ISI:000082237700001

- Lehaney, B. & Paul, R.J. 1994. Using Soft Systems Methodology to Develop A Simulation of Outpatient Services. *Journal of the Royal Society of Health*, 114, (5) 248-251 available from: ISI:A1994PK91800005
- Lewin, K. 1948. Action research and minority problems. In G. W. Lewin (Ed.), *Resolving social conflicts*. New York: Harper, 1948.
- Luyt, R. 2012. A Framework for Mixing Methods in Quantitative Measurement Development, Validation, and Revision : A Case Study. *Journal of Mixed Methods Research* 6(4) 294–316
- Macia-Chapula, C.A. 1995. Development of a soft systems model to identify information values, impact and barriers in a health care information system. *Journal of Information Science*, 21, (4) 283-288
- Malterud, K. 1995. Action research – a strategy for evaluation of medical interventions. *Family Practice*, 12, (4) 476-481
- Mazzocco, K., Petitti, D.B., Fong, K.T., Bonacum, D., Brookey, J., Graham, S., Lasky, R.E., Sexton, J.B., & Thomas, E.J. 2009. Surgical team behaviors and patient outcomes. *American Journal of Surgery*, 197, (5) 678-685 available from: ISI:000265859800026
- Mingers, J. 2000a. Variety is the spice of life: Combining soft and hard OR/MS methods. *International Transactions in Operational Research*, 7, (6) 673-691
- Mingers, J. & Brocklesby, J. 1997. Multimethodology: Towards a Framework for Mixing Methodologies. *Omega - The International Journal of Management Science*, 25, (5) 489-509
- Mingers, J. & Gill, A. 1997. *Multimethodology: The Theory and Practice of Combining Management Science Methodologies* Wiley, Chichester.
- Mingers, J. 2000b. An idea ahead of its time: The history and development of soft systems methodology. *Systemic Practice and Action Research*, 13, (6) 733-755 available from: ISI:000166394000003
- Mingers, J. & Rosenhead, J. 2004. Problem structuring methods in action. *European Journal of Operational Research*, 152, (3) 530-554 available from: ISI:000186246000002
- Mingers, J. & Taylor, S. 1992. The Use of Soft Systems Methodology in Practice. *Journal of the Operational Research Society*, 43, (4) 321-332 available from: ISI:A1992HM95600004
- Mitroff, I.I. & Featheringham, T.R. 1974. Systemic Problem-Solving and Error of 3Rd Kind. *Behavioral Science*, 19, (6) 383-393 available from: ISI:A1974AF72600004
- Munro, I. & Mingers, J. 2002. The use of multimethodology in practice – results of a survey of practitioners. *Journal of the Operational Research Society*, 53, 369-378
- Neily, J., Mills, P.D., Young-Xu, Y.N., Carney, B.T., West, P., Berger, D.H., Mazzia, L.M., Paull, D.E., & Bagian, J.P. 2010. Association Between Implementation of a Medical Team Training Program and Surgical Mortality. *Jama-Journal of the American Medical Association*, 304, (15) 1693-1700 available from: ISI:000283129700023

Niglas, K. 2004. *The combined use of qualitative and quantitative methods in educational research*. Tallin Pedagogical University.

ORAHS. *Operational Research Applied to Health Services*. Online Source 15-3-2012:
<http://orahs.di.unito.it/index.html>

Oslo Kommune. *Emergency medical care in Oslo*. Online Source 10-4-2012:
http://www.oslo.kommune.no/english/health_/

Partovi, S.N., Nelson, B.K., Bryan, E.D. & Walsh, M.J. 2001. Faculty triage shortens emergency department length of stay. *Academic Emergency Medicine*. 8, (10), 990-995.

Peters, M. & Robinson, V. 1984. The Origin and Status of Action Research. *The Journal of Applied Behavioural Science* 20 (2), 113-124

Petros, S.G. 2012. Use of a Mixed Methods Approach to investigate the support needs of Older Caregivers to Family Members Affected by HIV and AIDS in South Africa. *Journal of Mixed Methods Research*, 6(4) 275–293

Pidd, M. 2001. The futures of OR. *Journal of the Operational Research Society*, 52, (11) 1181-1190

Pidd, M. 2004. *Computer Simulation In Management Science* Chichester, Wiley.

Porter M. E. 1998. *Competitive Advantage*. The Free Press, New York

Potvin L., Bisset, S. L. & Walz L. 2010. Chapter 22 Participatory Action Research: Theoretical Perspectives on the Challenges of Researching Action, in *Qualitative Methods in Health Research*, Sage Publications, Los Angeles

Reason P. & Bradbury H. 2006. *Handbook of action research*. Sage Publications, London

Robbins, S.P. 1997. *Essentials of Organizational Behaviour* NJ: Prentice Hall, Upper Saddle River.

Robinson, S. 2004. *Simulation. The Practice of Model Development and Use* Chichester, Wiley.

Robinson, S. & Mendelson, A. L. 2012. A Qualitative Experiment: Research on Mediated Meaning Construction Using a Hybrid Approach. *Journal of Mixed Methods Research*, 6(4) 332–347

Rocheleau, D. 1995. Maps, numbers, text and content – mixing methods in feminist political ecology. *Professional Geographer*, 47, (4) 458-466

Rogers, T., Ross, N. & Spooner, D. 2004. Evaluation of a ‘see and treat’ pilot study introduced to an emergency department. *Accident and Emergency Nursing* 12, 24-27

Russ, S., Jones, I., Aronsky D., Dittus, R.S. & Slovis, C.M. 2010. Placing Physician Orders at Triage: The Effect on Length of Stay. *Annals of Emergency Medicine*, 56 (1) 27-33.

Sargent, R. G. 2009. Verification and validation of simulation models, *Proceedings of the 2009 Winter Simulation Conference*, eds: Rossetti, M. D., Hill, R. R., Johansson, B., Dunkin, A. and Ingalls, R. G., pp. 162-176.

Smithdaniels, V.L., Schweikhart, S.B., & Smithdaniels, D.E. 1988. Capacity Management in Health-Care Services - Review and Future-Research Directions. *Decision Sciences*, 19, (4) 889-919
available from: ISI:A1988AY41100014

Soremekun, O.A., Capp, R., Biddinger, P.D., White, B.A., Chang, Y., Carignan, S.B. & Browin, D.F.M. 2012. *The Journal of Emergency Medicine* 43 (3), 509-515

Soremekun, O.A., Biddinger, P.D., White, B.A., Sinclair, J.R., Chang, Y., Carignan, S.B. & Brown, D.F.G. 2011. Operational and financial impact of physician screening in the ED. *The American Journal of Emergency Medicine* 30, 532-539.

Stabell C. B. & Fjeldstad Ø. D. 1998. Configuring value for competitive advantage: on chains, shops and networks, *Strategic Management Journal*, 19, 413-437

Subash, F., Dunn, F., McNicholl, B. & Marlow, J. 2004. Team triage improves emergency department efficiency. *Emergency Medicine Journal* , 21, 542-544

Tako, A. A. 2008. *Development and use of simulation models in Operational Research: a comparison of discrete-event simulation and system dynamics*. PhD University of Warwick, Warwick Business School.

Terris, J., Leman, P., O'Connor, N. & Wood, R. 2004. Making an IMPACT on emergency department flow: improving patient processing assisted by consultant at triage. *Emergency Medicine Journal*, 21, 537-541.

Teye, J. K. 2012. Benefits, Challenges, and Dynamism of Positionalities Associated With Mixed Methods Research in Developing Countries: Evidence From Ghana. *Journal of Mixed Methods Research*, 6(4) 379–391

Travers, J.P. & Lee, F.C.Y. 2006. Avoiding prolonged waiting time during busy periods in the emergency department: is there a role for the senior emergency physician in triage? *European Journal of Emergency Medicine*, 13, 342-348

Vennix, J. A. M. Group Model-Building. *System Dynamics – Vol II. Encyclopedia of Life Support Systems (EOLSS)* available from <http://www.eolss.net/Sample-Chapters/C15/E6-63-05-05.pdf> (14.12.2012)

Vennix, J. A. M. 1999. Group model-building: tackling messy problems. *System Dynamics Review*, 15, (4) 379-401

Wells, J. S. G. 1995. Discontent without focus? An analysis of nurse management and activity on a psychiatric in-patient facility using a 'soft systems' approach. *Journal of Advanced Nursing* 21[2], 214-221. 1995.

Whyte, W. F. 1991. *Participatory Action Research*. Sage Publications, Newbury Park

Wiler, J.L., Gentle, C., Halfpenny, J.M., Heins, A., Mehrota, A., Mikhail, M.G. & Fite, D. 2010. Optimizing Emergency Department Front-End Operations. *Annals of Emergency Medicine* 55 (2), 142-160

Williams, B. 2005, *Soft Systems Methodology*. Online source 02.07.12:
<http://www.kapiti.co.nz/bobwill/ssm.pdf>

Wilson, J.C.T. 1981. Implementation of Computer-Simulation Projects in Health-Care. *Journal of the Operational Research Society*, 32, (9) 825-832 available from: ISI:A1981MC42700010

Wolmack, J. P. & Jones, D. 2003. *Lean Thinking*. Simon & Schuster, Inc. London

Yu, S. 2012 College Students' Justification for Digital Piracy : A Mixed Methods Study. *Journal of Mixed Methods Research*, 6(4) 364–378

Yu, J., Pressoir, G., Briggs, W. H., Vroh, I., Yamasaki, M., Doebley, J. F., McMullen M. D., Gaut, B. S., Nielsen, D. M., Holland, J. B., Kresovich, S. & Buckler, E. S. 2006. A unified mixed-model method for association mapping that accounts for multiple levels of relatedness. *Nature Genetics*, 38, (2) 203-208

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