

A Survey of Health Care Models that Encompass Multiple Departments

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Abstract

In this survey we review quantitative health care models to illustrate the extent to which they encompass multiple hospital departments. The paper provides general overviews of the relationships that exist between major hospital departments and describes how these relationships are accounted for by researchers. We find the atomistic view of hospitals often taken by researchers is partially due to the ambiguity of patient care trajectories. To this end clinical pathways literature is reviewed to illustrate its potential for clarifying patient flows and for providing a holistic hospital perspective.

Keywords: Operations Research, Health Care, Clinical Pathways, Literature Review

1 Introduction

In the 1980s it became clear that the reductionist method made famous by F.W. Taylor was causing the American manufacturing industry to lose perspective of their overall factory. The approach, which focused principally on analyzing individual components, failed to accurately account for their interactions. This narrow view was further compounded by the academic community which thrived on using reductionism for analyzing complex systems, ever the while increasing the gap between their research and actual practice. In contrast, Japanese manufactures focused on the system as a whole and endeavored to understand and exploit how individual components interacted and contributed to the overall goal of the system. This holistic approach allowed Japanese plants to become simpler, more flexible and more efficient than their American counterparts (Hopp and Spearman, 2001).

Nowadays, in health care there are natural pressures that cause managers to lose sight of the overall perspective and take an individual component approach. This is further complicated when an “individual component” is a living and breathing patient thus creating an emotional justification for the approach. Influenced by their culture and constrained by their professional duty and ethics, nurses and physicians have a learned and obligatory individual patient focus. Perhaps due to the complexity, organizational makeup or even their reward structure, often “management does not consider the total care chain from admission to discharge, but mainly focuses on the performance of individual units. Not surprisingly, this has often resulted in diminished patient access without any significant reduction in costs” (de Bruin et al., 2005).

Similar sentiments have been expressed by others reviewing health care operations. The following excerpt from Carter (2002) provides a summary with examples. “In my experience, one of the major causes of inefficiency in the health care system is what I call ‘localized expertise.’ People working in the health care system are very knowledgeable about their own area but have relatively

little understanding of what goes on in the next department. Doctors and nurses in the Emergency Department or in operating rooms do not really understand or sympathize with the problems faced by ward staff. People in hospitals have little appreciation for issues in long-term and home care. Occasionally, there are issues about ‘my work is more important than yours’ or ‘my problems are bigger than yours.’ More often, it is simply too difficult for people to get a real handle on the whole ‘system.’ This is where Operational Research professionals can play an important role”.

In this review we want to deal with these possibilities in more detail. This paper consists of four sections of which the second looks at the operational research literature. Specifically, the scope of health care models is examined to determine the extent in which modellers take a holistic approach to modelling and account for the complex interdepartmental relationships that are inherent in health care. Essentially the paper helps address the question, if researchers are reinforcing the atomistic hospital view of managers or if they are approaching hospital problems from a systems perspective.

Section 3 discusses the scope and limitations of clinical pathways. Hospitals have adapted tools from the manufacturing industry which have allowed them to gain a systems perspective on process improvement. Skinner (1985) describes “relatively new” tools available to manufactures that move them away from the reductionist techniques of Taylor and closer to an integrated and whole systems approach. One such tool is “critical pathways,” which is the predecessor of health care’s clinical pathways. Clinical pathways are essentially patient Gantt Charts (Pearson et al., 1995) with quality control checks (variance analysis). Clinical pathways are unarguably a holistic view of treatment, at least from a single patient’s perspective. Section 4 reviews clinical pathways literature and shows that from a single patient type perspective, a clinical pathway is a multidisciplinary description of a patient’s care trajectory. The section concludes with a discussion on how the two research communities have something to offer the other. The paper concludes with a brief discussion on how to overcome the challenges associated with models of large complex portions of a hospital.

All of the articles mentioned in this review are categorized in the online literature database OR-

chestra. ORchestra provides a comprehensive overview of scientific literature in the field of “Operations Research in Health Care” and can be accessed at <http://www.choir.utwente.nl/en/ORchestra>. ORchestra is maintained by the Center for Health Care Operations Improvement and Research (CHOIR), at the University of Twente.

2 Whole hospitals from the Departmental perspective

The review of literature in this section is intended to assess the extent in which operational researchers take a holistic approach to modelling patient flows. The section is divided as follows. Subsection 2.1 gives the used definition for “holistic models.” Subsection 2.2 describes the methodology used to identify relevant papers. Subsection 2.3 reviews models which are broadly classified according to application area within the hospital. Finally the section closes with a discussion and summary in Subsection 2.4.

2.1 Defining Holistic Models

Jun et al. (1999) completed a survey of discrete-event simulation models in health care citing over 100 articles and discussing the various applications in clinical settings. This widely cited paper “focuses on articles that analyse single or multi-facility health care clinics (for example, outpatient clinics, emergency departments, surgical centers, orthopedic department, and pharmacies).” With respect to patient flow and throughput, the paper discusses three areas of impact; first how patients are admitted or scheduled, second, how patients are routed within the clinic and finally how staff and resources are scheduled to match the demand. Jun et al. (1999) conclude, among other things, that “despite the upward trend of health care simulation studies ... there is still a void in the literature focusing on complex integrated systems” and suggest that this “may be due to the associated complexity issues and resource requirements.”

It is clear from Jun et al. (1999) that prior to 1999 simulation was not widely used as a tool for modelling holistic (complex integrated) health care systems. When considering the advances in computers and simulation software coupled with the ever increasing pressures on hospitals, it begs the question if this void has since been filled. In this section we investigate this and focus on patient flow models with a scope that includes more than one department or unit. Although “more than one department or unit” is hardly a rigorous definition of a holistic health care model, it is thought that the vague but inclusive definition allows for a more complete review. In the interest of clarity, a short list of model types that are excluded from this review follows. Undoubtedly many of them indirectly influence patient flow across multiple department but their main objectives are different.

- Developing a surgical schedule and only considering resources within the Department of Surgery.
- Scheduling a single outpatient clinic without modelling where patients come from or where they are going to.
- Reducing waiting times within a single clinic or service.
- Reducing access times by analyzing only a single department’s resources.
- Scheduling of physicians or hospital staff.

2.2 Identifying papers

As a starting point in identifying relevant literature, a list of all articles citing (Jun et al., 1999) was compiled. Using Google Scholar, 70 articles were identified. Of these, 20 (28.6%) describe models containing more than one department or unit, 15 (21.4%) are instructional/tutorial in nature, seven (10.0%) are surveys, and 28 (40.0%) are applications and case studies within a single department or unit. The remaining papers mentioned in this section either cite or are cited by one of the 20

papers, identified as describing a model with a scope of more than one department or unit. In total the systematic review resulted in 88 articles describing models which encompass multiple hospital departments.

2.3 Common Model Scopes

In the health care literature pockets of attention are focused primarily on Surgery, Emergency Medical Care, Inpatient Ward, Outpatient Clinics and Diagnostics (e.g. Imaging, Laboratory Medicine) and Pharmacy services. The importance and influence of each area on the hospital as a whole is discussed. The emergency department, with its consistent rise in admissions (Capewell, 1996), is often described as a crisis (Hanratty and Robinson, 1999) and has even been described as a threat to the future of the NHS (Blatchford and Capewell, 1997). The surgery department and in particular “the master surgery schedule can be seen as the engine that drives the hospital” (Beliën et al., 2006). The operation of both services depends heavily on the available capacity of the downstream inpatient ward. Prompt and efficient service within an outpatient facility can improve patient satisfaction (Dansky and Miles, 1997; Huang, 1994) resulting in patients being more likely to follow medical treatment plans (Wartman et al., 1983) and thus reducing the need for patients to have surgery or visit the emergency department. Furthermore, “unlike most of the component parts of a general hospital, which are designed to cater for patients with particular kinds of illnesses, the services of diagnostic radiology departments are utilized by almost every category of patient which enters the hospital system. Hence, efficient utilization of X-ray facilities is a necessary condition for overall hospital efficiency” (O’Kane, 1981). The following subsections describe models found in these focal areas and the last subsection is used to describe other models which do not readily fit this broad classification.

2.3.1 Emergency Medical Care

When one thinks of the Emergency Medical Care, the Emergency Department (ED) is usually the first of the many components that comes to mind. However there are a multitude of external groups supporting the ED including, the upstream paramedics, the downstream wards, and the parallel stream support services such as Diagnostic Imaging (DI), Lab and Pharmacy. For a more detailed account of these and the many other service interactions within emergency medical care see (Blake et al., 1996; Hall, 2006; Fletcher and Worthington, 2007).

Most operational research studies of the ED relate to access time and consider the layout of the ED, the prioritization of patients, and congestion. The models have “generally assumed that the processes outside the ED have little direct impact on its overall operations” (Carter and Blake, 2004). However, studies without an operational research focus, such as those by Derlet and Richards (2000); Drummond (2002) identified factors causing ED overcrowding that are outside of direct control of the ED. Mainly these factors are lack of beds for patients admitted to the hospital, delays in service provided by radiology, laboratory and ancillary services, difficulty in arranging follow-up care and difficulty in the transfer process. Within the reviewed papers only 12 models have been identified that explicitly account for processes outside of the ED. The scope of these models and the techniques used are discussed below.

All but one of the papers explicitly consider the ED and ward relationship in their models. Takakuwa and Shiozaki (2004); Bagust et al. (1999) use discrete event simulation to investigate the influence of the recovery ward on ED wait times. Lane et al. (2000) also consider this relationship but use a systems dynamics approach. Carter and Blake (2004) describe the use of simulation to analyze the cause and relationship of overcrowding in multiple EDs. Ceglowski et al. (2007) use data mining techniques to identify ED/Ward bottlenecks. Altinel and Ulas (1996) use discrete event simulation for a surgical ED which includes a regular-care unit, a semi-intensive care unit, and

an intensive-care unit. In addition to the wards, the models of Criswell et al. (2007); Blasak et al. (2003); Samaha et al. (2003); Chick et al. (2003) consider the relationship between the ED and DI or the Lab.

A model with a slightly larger scope is described by de Bruin et al. (2005). Their model, although limited to Cardiac Care, incorporates both a normal care ward and an intensive care unit (ICU). By studying this relationship using queuing theory the authors contend that “raising occupancy rates of hospital management is unrealistic and counterproductive” and relate refused admission to the unavailability of downstream beds.

The above papers explicitly model the downstream wards but, like many operational research specialists, they model arriving patients with a distribution. The advantages of arrival distributions in emulating their stochastic nature are described in detail with examples in (Harper and Shahani, 2002). When done correctly arrival distributions are a statistically accurate reflection of patient arrivals, allowing the researcher to exclude upstream processes from the model. On the downside however, by excluding the upstream processes, many potential improvement opportunities may be overlooked. For example, these models reflect the variability by which patients are referred to a department but are ignorant to its causes. It could be caused by natural patient illness factors or be induced by operational factors such as poor planning and scheduling in the upstream process. As a result, great effort may be spent on developing strategies to deal with the variation instead of focusing on the root problem in the appropriate department. Furthermore, improvements due to better coordination between departments (or even a more appropriate balance of resources between departments) are most certainly not accounted for when the transition of patients between departments is modelled by arrival distributions.

Brailsford et al. (2004) state that they give a “whole-system review of emergency and on-demand health care” and consider emergency medical care well beyond the boundaries of the ED. The focus is on the complete emergency health care system and therefore considers departments feeding the

Paper	Departments	Approach
(Ceglowski et al., 2007)	ED, Ward	Data Mining
(Criswell et al., 2007)	ED, DI	Petri Nets
(de Bruin et al., 2005)	ED, ICU, Ward	Queueing Theory
(Brailsford et al., 2004)	Referrals, Ambulances, ED, Lab/DI, ICU, Ward	Systems Dynamics
(Takakuwa and Shiozaki, 2004)	ED, Ward	Simulation
(Carter and Blake, 2004)	ED, Ward	Simulation
(Blasak et al., 2003)	ED, Lab/DI, Ward	Simulation
(Samaha et al., 2003)	ED, Lab/DI, Ward, OR	Systems Dynamics
(Chick et al., 2003)	ED, Lab/DI, Ward	Simulation
(Lane et al., 2000)	ED, Ward	Simulation
(Bagust et al., 1999)	ED, Ward	Simulation
(Altinel and Ulas, 1996)	ED, OR, ICU Ward	Simulation

Table 1: The extent to which departments surrounding the Emergency Department are explicitly modelled

ED, such as ambulance services and primary care. Furthermore downstream departments including wards and social services are also included. The systems dynamics model connects the departure rates (outflows) of one department with the arrival rates (inflow) of other departments, resulting in a model that is sensitive to the fact that a small change to one part of the system can have considerable impact elsewhere. With this robust model the authors are able to recommend a variety of approaches, related to admission practices, which may reduce the demand for impatient beds.

Table 1 summarizes the extent to which the papers mentioned in this subsection explicitly model the surrounding processes. It is not surprising that most of these papers include the downstream ward. Many studies claim that the lack of down stream beds is the “primary reason hospitals go into diversion” (IHI, 2003). However these studies and others (Hall, 2006), insist that all inputs and outputs be considered when addressing patient flow issues. Additionally, studies on congestion (Derlet and Richards, 2000; Drummond, 2002) state that many of the causes are outside of the ED. Yet this review only identified 12 models that explicitly account for interactions between the ED and adjacent departments.

2.3.2 Surgical Care Services

Surgical care, like emergency care, does not operate in isolation, it “encompasses a continuum of activities through diagnostics, pre-operative, operative, and post-operative stages” (Sobolev et al., 2008). In their article, further details on this ‘continuum of activities’ are given. Pham and Klinkert (2008) also provide a description and flow diagram of the typical activities of a surgical department. For an up-to-date bibliography of operating room management articles see (Dexter, 2009).

Looking at the literature on surgical care services two themes are recurrent. First, a gate keeping system -the surgical schedule- is commonly used for adjusting the Operating Room’s (OR) function. By changing when and what patients arrive, managers are able to predict and possibly balance resource usage. For an overview of how hospitals develop this schedule see (Wachtel and Dexter, 2008; van Houdenhoven et al., 2007; Blake and Carter, 1997). The second common model theme is waiting list management. These models often consider how waiting patients are impacted by resources levels, resource distribution and patient priority schemes. As is the topic of this review, the extent to which these models consider adjacent departments is discussed in the following paragraphs.

“Scheduling systems, which control the flow of patients into the surgical arena, are frequently cited as a primary means of improving resource utilization” (Lowery and Martin, 1989). The development of a surgery schedule and the planning of patients is often described as a multistage approach (Blake and Donald, 2002; Beliën and Demeulemeester, 2007) and, as is the case with ED models, often consider the impact of downstream bed availability. Kim and Horowitz (2002) examine the conflict created by elective patients being scheduled solely according to surgeon and operating room availability and under the assumption that an ICU bed will be available. The authors use a computer simulation to test a quota mechanism that aims to more evenly distribute the elective cases requiring admission to the ICU. Carter and Blake (2004) use simulation to model the patient care trajectory starting from the surgical schedule and continuing through the operating room, the

recovery room, the intensive care units and the regular inpatient wards. For various allocation of operating room time, their model forecasts resulting beds and nursing levels. Using mixed integer programming model, Santibanez et al. (2005) show that “by reallocating the surgical specialties in the block schedule it is possible to reduce resource requirements needed to care for patients after surgery, while maintaining the throughput of patients.”

Currie et al. (2003) describe a computer simulation that supports the care of patients with hip fractures. The simulation includes patient’s presenting with a hip fracture, preoperative care, surgery, postoperative care, rehabilitation and discharge. The main objective of the model is to “simulate hip fracture care delivery reconfigured to comply with the national guideline on hip fracture care. This allowed exploration of how service change affected outcomes and patterns of resource use.” With their multi-agent model it is possible for the service to explore “scenarios depicting varying degrees of guideline compliance.”

Searching for articles that cite (or are cited by) the articles mentioned in the above paragraph quickly reveals an extensive literature on the subject of operating room scheduling. “A substantial and mature operations research literature describes techniques for manipulating the master surgical schedule, or the order of cases on the daily operating list, to maximize institutional goals or objectives” (Blake and Donald, 2002). For an extensive bibliography on operating room scheduling and planning see (Cardoen et al., 2008). From this look at surgical scheduling models, it appears that studies often consider a multitude of factors that are internal to the services, such as staffing and equipment, but usually only consider a single external factor, inpatient beds.

Other authors describe more general approaches to ensure the impact of the surgery schedule on adjacent processes is accounted for. Sobolev et al. (2008) present a statecharts paradigm as a method “for constructing a discrete-event simulation model of the perioperative process.” They argue this approach is powerful for “identifying likely responses to changes in the peri-operative process.” Beliën et al. (2006) proposes software for visually displaying the impact of the master surgical

schedule on a compilation of dependent resources, including beds, human resources (e.g. nurses, anaesthetists), specialized instruments and the radiology department.

Higher resource utilization and less surgery cancellations can result from these and other alterations in the surgical schedule. This clearly has an impact on throughput and correspondingly on elective patient waiting times (VanBerkel and Blake, 2007; Cardoen et al., 2008). However, waiting list management models for elective surgery often take the surgical schedule for granted and considers the allocation of resources (mainly operating room time and inpatient beds), and patient priority schemes as the variables (VanBerkel and Blake, 2007). These models are often specific to a surgical specialty (Wright, 1987), and are primarily used to quantify waiting list concerns, highlight imbalances in resources, or suggest ways to increase throughput. Outputs from the model may be used as clout for divisions when they jockey for a greater allocation of resources (Blake, 2005) or as decision support for selecting patients (Everett, 2002). Waiting list management is further complicated by the social and political environment and their ethical implications (Pitt et al., 2003) as a rationing device (Gross, 2004; Martin and Smith, 1999). For a summary of waiting list practices and issues from a Canadian perspective see (Blake, 2005) and from a National Health Services (UK) perspective see (Worthington, 1991; Dimakou et al., 2008). For a discussion on the appropriateness of patient priority schemes see (Oudhoff et al., 2007).

In Table 2 a complete list of the identified papers relating the operation of OR with surrounding departments is given. As was also the case in the preceding subsection, many authors explicitly model the downstream ward processes but represent upstream processes by statistical distributions.

The models discussed in this subsection all consider interactions with departments outside of the surgery department (the principle department under study). All recognize the importance of considering the availability of downstream ward capacity when making decisions in the OR.

Paper	Departments	Approach
(Pham and Klinkert, 2008)	OR, PACU, ICU	Mathematical Programming
(Masursky et al., 2008)	OR, Anesthesia	Statistics Methods
(van Houdenhoven et al., 2008)	OR, ICU	Mathematical Programming
(van Oostrum et al., 2008)	OR, ICU, Ward	Mathematical Programming
(Sobolev et al., 2008)	Waiting lists, OR	Simulation
(Testi and Tānfani, 2008)	Waiting lists, OR	Mathematical Programming
(McGowan et al., 2007)	OR, PACU, Ward	Process Reengineering
(Santibāñez et al., 2007)	Waiting lists, OR, Ward	Mathematical Programming
(Testi et al., 2007)	Waiting lists, OR, Ward	Mathematical Programming
(VanBerkel and Blake, 2007)	Waiting lists, OR, Ward	Simulation
(Jebali et al., 2006)	OR, PACU, Ward,	Mathematical Programming
(Sokal et al., 2006)	OR, PACU	Statistics Methods
(Beliën et al., 2006)	OR, DI	Software
(Bowers and Mould, 2005)	OR, Ward	Simulation
(Calichman, 2005)	OR, PACU, Ward	Mathematical Programming
(Santibanez et al., 2005)	Waiting lists, OR, ICU, Ward	Mathematical Programming
(Carter and Blake, 2004)	OR, PACU, ICU, Ward	Simulation
(Dexter and Lubarsky, 2004)	OR, PACU, Ward	Statistics Methods
(Currie et al., 2003)	OR, PACU, Ward, Rehab	Simulation
(Guinet and Chaabane, 2003)	OR, Ward	Mathematical Programming
(McManus et al., 2003)	OR, ICU	Statistics Methods
(Bowers and Mould, 2002)	OR, Ward	Simulation
(Kim and Horowitz, 2002)	OR, ICU, Ward	Simulation
(Blake and Donald, 2002)	OR, Ward	Mathematical Programming
(Dexter et al., 2002)	OR, ICU, Ward	Mathematical Programming
(Everett, 2002)	Waiting lists, OR, Ward	Simulation
(Lovejoy and Li, 2002)	Waiting lists, OR	Mathematical Programming
(Everett, 2002)	Waiting lists, OR, Ward	Simulation
(Ramis et al., 2001)	OR, DI	Simulation
(Dexter et al., 2000)	Waiting lists, Clinic, OR	Software
(Epstein and Dexter, 2000)	OR, Materials Management	Simulation
(Kim et al., 2000)	ED, ICU, OR	Simulation
(Rotondi et al., 1997)	OR, PACU	Software
(Sier et al., 1997)	OR, Ward	Mathematical Programming
(Wright, 1987)	Waiting lists, OR, Ward	Simulation
(Kwak et al., 1976)	OR, Ward	Simulation

Table 2: The extent to which departments surrounding the Operating Room are explicitly modelled

2.3.3 Inpatient Bed Wards

The strong relationship between the aforementioned departments (surgical care and emergency care) and the inpatient wards is apparent from Tables 1 and 2 and the preceding subsections. With this emphasis on wards and the fact that they are described as a hospital's "most expensive resources" (Black and Pearson, 2002), it is not surprising to find a pocket of literature describing models with a focus solely on inpatient ward capacity. What distinguishes the inpatient ward models from the models presented earlier is that these papers focus primarily on the inpatient bed resources.

A comprehensive simulation for bed capacity planning is presented by Harper and Shahani (2002), which exposes the shortsightedness of hospital wide bed occupancy goals. "An acceptable occupancy, with its corresponding refusal rate, is a complex function of the patient case mix, the size of the bed compliment and the variability in patient [length of stay]". Similar sentiments are expressed in (de Bruin et al., 2005). Harper and Shahani (2002) also list 15 papers that address bed requirements using queueing models, integer programming, forecasting, or simulation and demonstrate the disadvantages of commonly used deterministic approaches. Other bed capacity studies consider critical care wards (Vissers and Beech, 2005; Costa et al., 2003; Nguyen et al., 2003; Bonvissuto, 1994), general inpatient wards (Kokangul, 2008), the distribution of beds (Akkerman and Knip, 2004; Nguyen et al., 2005), the possibility of intermediate care wards (Utley et al., 2003) and controlling ward occupancy through admission practices (Vissers, 1998; Adan and Vissers, 2002). For further literature on bed capacity planning see (Kokangul, 2008).

Cochran and Bharti (2006a) concurs with Jun et al. (1999) that the literature includes a great deal of "simulation models which vary enormously in complexity but are often unit specific." In addition to simulation, Cochran and Bharti (2006a) draw similar conclusions about the application of queueing theory in health care. "Although there is a vast literature available on the application of queueing theory in health care, none of the reviewed papers reported using queueing theory network

models for systems of more than one unit.” In two papers the authors use a step-by-step methodology “for analyzing hospital flow using queuing network and simulation models with the emphasis on solutions to peak flow periods.” With the queuing theory model the authors are able to find the system bottleneck and recommend resource levels for utilization balancing across the hospital. “Although [Queueing Network Analysis] was very effective in balancing the system quickly and easily, it has limitations. It does not consider time-dependence. It uses only the mean value of the length of stay in a unit bed ... It does not easily account for bed blocking.” To combat this, a discrete event simulation is presented to provide insight into waiting times, throughput, and congestion. The advantage of hybrid queuing/simulation models is discussed in detail in (van Dijk and van der Sluis, 2008; van Dijk, 2000).

As a starting point Cochran and Bharti (2006b) apply their hybrid queuing/simulation methodology to an obstetrics hospital because “it contains all of the features of a full service hospital but on a simpler scale.” With the simulation model the authors are able to recommend how to “minimize blocking of beds from upstream units.” A second study by Cochran and Bharti (2006a) is of a 411 beds, 13 units hospital, where patients are admitted via the ED, OR or direct admission to medical units (outpatient clinics are not included). The queuing analysis provided insight into bed balancing across the wards while the simulation is used to maximize flow through the system.

Besides bed capacity decisions, the operation of inpatient wards is also studied. Typical impediments to patient flow in the inpatient wards, are outlined by Hall (2006). In summary they include long patient discharge processes, long turn around times between patients, poor tracking of bed inventory and lack of information on new patients forcing wards to be reactive instead of proactive. Other anecdotal accounts of inefficiency made by ward staff to an author include; overworked staff underreporting available beds as a means to control workload, physicians keeping patients longer than necessary as a way of reserving beds and the inability of family members to pick up to-be-discharged patients in a prompt manner. Most models represent resources by beds (Griffiths et al.,

2005), demand by patient lengths of stay (Vasilakis and Marshall, 2005) and leave many of these operational issues unaddressed.

Even the best discharge planning does not help when there is no downstream capacity. Patient's whose medical treatment is complete but cannot leave the hospital are often referred to as "alternative level of care patients" (Beland et al., 2006) or as "bed blockers" (Rubin and Davies, 1975). The cause of bed blocking can be "the reductions in numbers of beds in nursing homes, problems in funding from social service budgets, and waits for assessments from therapists or social services, for community services, or for equipment to be ordered, delivered, and installed" (Black and Pearson, 2002). This problem is further compounded by poor coordination between the hospital and long term/social care, as discussed in (Johansson, 1997). The effect of bed blockers is often measured by the average fraction of beds occupied by patient's whose medical treatment is complete. The range of this fraction has been reported as low as 0.5% (Renwick et al., 1992) to as high as 35% (Johansson, 1997; Drummond, 2002). Not surprisingly, Drummond (2002) found the affect of blocked beds was not limited to the wards and that the impact was also felt in the ED and critical care where patients await admission to a bed. For a discussion on an initiative to integrate the hospital care with the nursing home care for elderly persons, see (Beland et al., 2006). For a study relating bed blocking with community care and with the ED see (Mayhew, 2008). Although this is clearly an area of importance for efficient use of inpatient beds it is not widely included in models of impatient wards.

After examining three major portions of hospitals (Emergency Medical Care, Surgical Care and the Inpatient Wards), we see an emphasis on the interaction between wards and the ED and Surgery department. Five articles (Kolker, 2008; Lane et al., 2000; Taylor and Lane, 1998; Kim et al., 1999; Wright, 1987) consider the competing nature of the ED and Surgery department. This interaction, although perhaps not intuitive, is important because both services forward their inpatients to bed wards. Even though many hospitals segregate their wards based on these services, it is often the case that they share beds at times of high demand, which happens to be the time of interest in most

Paper	Departments	Approach
(Kolker, 2008)	ED, OR, ICU	Simulation
(Mayhew, 2008)	Ward, Community Care, ED	Data Analysis
(Cochran and Bharti, 2006a)	OR, ICU, Ward	Queueing Theory & Simulation
(Cochran and Bharti, 2006b)	OR, ICU, Ward	Queueing Theory & Simulation
(Beland et al., 2006)	ED, Ward, Home Care	Randomized Controlled Trial
(Nguyen et al., 2005)	Multiple Wards	Statistical Methods
(Vissers and Beech, 2005)	OR, ICU	Mathematical Programming
(Akkerman and Knip, 2004)	Waiting lists, ICU, Ward	Queueing Theory & Simulation
(Costa et al., 2003)	ICU, Ward	Simulation
(Nguyen et al., 2003)	ICU, Ward	Statistical Methods
(Utley et al., 2003)	Intermediate Care, Ward	Queueing Theory
(Harper and Shahani, 2002)	ED, Ward	Simulation
(Drummond, 2002)	ED, Ward	Simulation
(Adan and Vissers, 2002)	OR, ICU, Ward	Mathematical Programming
(Lane et al., 2000)	ED, OR, Ward	Systems Dynamics
(Kim et al., 1999)	ED, OR, Ward	Simulation
(Taylor and Lane, 1998)	ED, OR, Ward	Systems Dynamics
(Vissers, 1998)	OR, Ward	Process Reengineering
(Bonvissuto, 1994)	ICU, Ward	Data Analysis
(Wright, 1987)	ED, OR, Ward	Simulation

Table 3: The extent to which departments surrounding the Inpatient Wards are explicitly modelled models.

The articles highlighted in this subsection are summarized in Table 3.

2.3.4 Ambulatory Care

The extent to which ambulatory care clinics are considered as part of a larger system is described in detail in (Matta and Patterson, 2007). The authors provide a detailed discussion on the lack of cohesion and conclude that “despite the interrelatedness and the fact that patients are shared between facilities, outpatient care systems are rarely evaluated as a coordinated subsystem of a hospital.” A rich literature on outpatient scheduling, albeit mainly focusing on a single department, started with Bailey (1952) and is summed up in a comprehensive survey by Cayirli and Veral (2003).

Of the papers that cite (Jun et al., 1999), four are relevant to this subsection, in that the mod-

els comprise of more than one department. All of these papers describe models of ambulatory care centres, which are essentially clusters of outpatient services situated together. Matta and Patterson (2007) developed a comprehensive framework to measure the performance of “multi-facility outpatient centres.” The paper includes a case study of an oncology centre, which includes one surgical clinic, two medical clinics, one treatment clinic and 14 diagnostic testing facilities. Jiang and Giachetti (2008) describe a care centre which has multiple outpatient clinics located together and also managed as a single department. Their model uses a multi-class open queueing network and a simulation to model the patient routing between the evaluation, x-ray, lab, treatment and medication components in the urgent care centre. Their effort to achieve higher throughput by putting these components in parallel, proved fruitless as the bottleneck activity (evaluation and re-evaluation by physicians) was the dominating cause of patient delays. van der Meer et al. (2005) model a musculoskeletal unit, which the authors describe as “an innovative concept that was designed to integrate the activities of orthopaedics and rheumatology with specialist physiotherapy and podiatry.” The authors describe five iterative simulation models, with the first four being typical what-if case studies applied within one hospital. In the fifth simulation the model is expanded to incorporate the “full integration of outpatient services across two hospitals” and is used to evaluate a new two-stage triage process.

The model described by Ashton et al. (2005) is different to the others in this subsection, in that it describes a facility housing many ambulatory clinics, each of which has its own staff and appointment systems. The community based ambulatory care centre consists of seven services (ECG, Dentistry, Homeopath, Chiropody, Eye Care, Dietitian and Family Planning) in addition to four shared treatment rooms. Their simulation balances the patient loads of the groups and stimulates staff to “understand interactions across the whole picture, rather than just in the part that they would normally be involved with.”

A final consideration for this subsection is the interaction of patients within the same department

Paper	Departments	Approach
(Jiang and Giachetti, 2008)	Outpatient Clinics, DI/Lab	Queueing Theory & Simulation
(Matta and Patterson, 2007)	Outpatient Clinics, DI/Lab, Pharmacy	Process Reengineering
(van der Meer et al., 2005)	Mulitple Outpatient Clinics	Simulation
(Ashton et al., 2005)	Mulitple Outpatient Clinics	Simulation

Table 4: The extent to which departments surrounding the Outpatient Clinics are explicitly modelled

but at different stages of their care. As an example, most departments have the patient categories “new” and “return” for which the characteristic of the appointment can be different. This situation can be considered analogous to that of a patient visiting two different departments in which the outcome of the first appointment affects the second. Such a situation is investigated and discussed in (Cayirli et al., 2006). The authors conclude “that patient sequencing has a greater effect on ambulatory care performance than the choice of an appointment rule, and that panel characteristics such as walk-ins, no-shows, punctuality and overall session volume, influence the effectiveness of appointment systems.”

A summary for this subsection is given in Table 4.

2.3.5 Diagnostic Services and Pharmacy

In this subsection three essential departments providing a supporting role in patient care, are considered. Specifically, this subsection encompasses models for DI, laboratory medicine and pharmacy. For clarity we offer definitions of each department. The DI department interprets medical images such as X-rays, CT scans, nuclear medicine scans, mammograms and sonograms (Conforti et al., 2007). A typical laboratory medicine department consists of core lab, microbiology, chemistry, blood transfusion services, and other hematological services. The pharmacy oversees the distribution of medication and ensures patients receive appropriate amounts which do not interact. Pharmacy’s involvement extends beyond the walls of the pharmacy and includes consulting with staff during a patient’s admission, length of stay, transfer and discharge (Hall, 2006). For details on the operation

of UK pharmacy systems see (Dean et al., 1995). Other supporting services such as social work, physiotherapy and occupational therapy, are not considered herein.

Of the over 70 papers citing (Jun et al., 1999) none describes a multi-departmental model with a focus on diagnostic services. This deficiency in literature is also noted in (O’Kane, 1981; Brasted, 2008; Fletcher and Worthington, 2007). Without a single article as a starting point the previously described methodology for searching literature was abandoned. In this subsection literature is identified by reviewing all articles that cited any of the six papers Jun et al. (1999) discusses related to radiology, hematology and pharmacy. As stated previously only those paper describing multi-department models are included.

Using a simulation model, Dean et al. (1999) investigate the “relationship between the ward pharmacist’s visit schedule and the delay between prescription of non-stock drugs and their delivery to the ward.” The authors are cognizant to the fact that the distribution system is itself multidisciplinary and when changed, it affects “nursing and medical staff throughout the hospital as well as patients.” For their case study the authors recommend the best time for pharmacists to visit the ward, and give a general conclusion that this best time can vary from ward to ward. Also using simulation, Wong et al. (2003) model the medication ordering, dispensing and administration process to determine the potential benefits of replacing the paper based process with an automated system. Centeno et al. (2000) simulate a variety of scenarios to improve the working relationship between the OR and DI.

The operation of diagnostic services can be described as analogous to the operation of ambulatory clinics, particularly in terms of patient scheduling (Cayirli and Veral, 2003). One difference however is that a coordinated approach is perhaps even more important for the overall patient care trajectory. Decisions on a patient’s treatment may be placed on hold while waiting for the results from an X-ray, blood test or other test.

Table 5 summarizes the scope of the models discussed in this subsection.

Paper	Departments	Approach
(Wong et al., 2003)	Wards, Pharmacy	Simulation
(Centeno et al., 2000)	OR, DI	Simulation
(Dean et al., 1999)	Wards, Pharmacy	Simulation

Table 5: The extent to which departments surrounding radiology, laboratory medicine and pharmacy are explicitly modelled

2.3.6 Geriatric Care and Mental Health Care

Three papers have been identified describing models which do not readily fit the classification scheme used in this paper. However they describe models that look at the system of care and not simply a single department in the care chain. This subsection discusses these models, of which two are for mental health care and one is for geriatric care.

Kommer (2002) developed a model incorporating the various living situations of the mentally disabled in The Netherlands. The “linear recursive stock flow model” is “developed from a dynamical systems point of view and incorporates the number of clients on the waiting list and the capacities of institutional and semi-institutional care.” This macro level approach allows the entire system of residential care to be studied from a national perspective. Although the model is hampered by poor data, it did help pinpoint “critical elements in the waiting list discussion” and stimulated systems thinking by highlighting the effect of an increasing inflow and a stagnating outflow on patient waiting list.

Koizumi et al. (2005) apply queuing theory with blocking to analysis the congestion in a mental health system. The model encompasses the interaction of the community, acute hospitals, extended acute hospitals, residential facilities and support housing. The analysis identifies the bottleneck resource and concludes that when planning, the transient behavior of this system is more importance than the steady-state. In their case study the authors find that “the shortage of a particular type of facility may have created ‘upstream blocking’. Thus removal of such facility-specific bottlenecks may be the most efficient way to reduce congestion in the system as a whole.”

Paper	Departments	Approach
(Kotiadis, 2006)	Wards, Rehabilitation, Recuperative Care	Simulation
(Koizumi et al., 2005)	Multiple Mental Health Care Facilities	Queueing Theory
(Kommer, 2002)	Waiting lists, Multiple Mental Health Care Facilities	Systems Dynamics

Table 6: The extent to which departments surrounding radiology, laboratory medicine and pharmacy are explicitly modelled

Kotiadis (2006) describes “a simulation study of a complex integrated health care system for older people, call Intermediate Care.” When describing the scope to be studied the stakeholder “made it quite clear that they were keen to evaluate the whole Intermediate Care system and not just individual services.” The system consisted of ten services, Community Access Rehabilitation Team, a Day Hospital, a Recuperative Care service, and seven rehabilitation wards. Due to the complexity and the short time since the inception of Intermediate Care it was not exactly clear how these services interacted and/or complemented each other. In their paper the authors provide an extensive description of a Soft Systems Methodology to first develop an understanding of the problem and then to determine a conceptual model. From this conceptual model a simulation was developed of the ideal system and was used to evaluate the utilization and to identify service gaps.

Table 6 summarizes the scope of the models discussed in this subsection.

2.4 Summary

Health care modelling literature is ripe with studies on scheduling, resource utilization, and patient flow. However, these studies are often confined to the operation of a single department, ignoring many of the complex relationships that exist between them. As an example, patient arrival patterns are often modelled with statistical distributions instead of explicitly as a consequence of previous care. This disjointed approach fails to offer coordinated patient trajectories and essentially represents a hospital as a collection of processes mindlessly receiving patients from, and feeding patients into, buffers. From industry, we have learned that disjointed and unbalanced production lines lead to high

costs. Such environments have high buffer capacity, much work-in-progress, long product cycle times and are plagued with inefficiencies. It is arguable that the impacts of disjointed operations are even more distressing in health care settings. Waiting patients, unlike waiting products, may phone the hospital if their wait is excessive, be prioritized and reprioritized, require ongoing care and cause other excessive coordination and management efforts. For inpatients these costs are high and direct, making the reduction of length of stay of patients a priority in hospitals and a common goal of many studies. For outpatients the costs associated with waiting for access to a service are not direct, often hidden, and not addressed in the health care literature. In addition to the administrative costs, the quality of life costs for patients cannot be understated. Besides the obvious extended period of time in poor health, there is anxiety associated with waiting, the possibility of further health deterioration, the loss of confidence in the hospital or physician, and furthermore, the compounded effect of all of these factors together.

As was shown in this section, some headway in this area is evident in the health care modelling literature. Many models consider the impact of their operations on the downstream inpatient wards. Typical examples include bed occupancy being dictated by the operating room schedule, and ED congestion being caused by inability to admit patients to an already overcrowded ward. There is a pocket of literature concerning a hospital's inability to discharge patients into long-term care. Hospitals are developing ambulatory care centres that locate multiple specialties together so that a patient's ambulatory treatment can, at the least, happen in the same space, and at the best, be efficiently coordinated. Pharmacy services identify that the drug distribution network is multidisciplinary and has significant impact on the work of physicians and nurses in addition to patient care implications.

This section presents a review of models used to examine issues related to patient flow. The purpose of the section is to determine the extent in which models account for interactions between the main department under study and adjacent departments. The review contains 88 papers describing patient flow models that considered resources from two or more hospital departments. This amount

	Simulation	Mathematical Programming	Systems Dynamics	Queueing Theory	Other
Emergency Medical Care	7		2	1	2
Surgical Care Services	14	14			8
Inpatient Bed Wards	8	2	3	4	6
Ambulatory Care	3			1	1
Diagnostic Services and Pharmacy	3				
Geriatric Care and Mental Health Care	1		1	1	

Table 7: Frequency of common modelling approaches in each hospital area

is consistent with findings of other authors (Jun et al., 1999; Fletcher and Worthington, 2007) who concluded that although there is an abundance of models for health care processes, few consider multiple units or departments. All of the 88 models include the interactions with downstream departments. This highlights the importance that congestion in one department is often related to an inability to forward patients to a succeeding department.

Of the 88 models, 30 explicitly model the interaction with upstream departments (i.e. those departments which their patients are referred from). The remaining models use distributions to capture the variations associated with arrival patterns. Although this method is preferential to using only averages it fails to distinguish between the variation caused by the random nature of illnesses and the variation induced by preceding departments. Such oversight may result in implementing complex policies to deal with variation instead of eliminating it at the source.

Finally, only 13 of the 88 models consider how diagnostic health care departments impact the flow of patients through the hospital. These departments provide an intermediate service, usually of a diagnostic nature, such as radiology and pharmacy. Although many patients require blood work, x-rays or other exams in order to be properly treated or diagnosed, very few models include their interactions with the main department under study.

To offer some insight into the common modelling approaches, Table 7 lists the frequency that each approach is used in each hospital area.

3 Whole hospitals from a Patient Flow Perspective

Within this review we identified 88 papers dealing with models having a scope of more than a single department. One challenge in developing multidepartment models is that “hospitals are highly complex systems that are poorly understood” (Kopach-Konrad et al., 2007). “More sophistication in understanding the requirements of the environment, rather than ever more-complex models, is required” (Proudlove et al., 2007). To gain that understanding it is suggested that a hospital be described by the flow of its patients (Vissers and Beech, 2005; Walley et al., 2006; Villa et al., 2008; Cote, 2000). However, “patient care plans for the individual patient are rarely formally recorded, as such, they tend to evolve with the patient stay, and exist in a piece-meal fashion in the minds of physicians, nurses, and discharge planners” (Kopach-Konrad et al., 2007). The importance of defining patient pathways and the associated difficulties are discussed in (Dronzek, 2001). Not knowing what a typical patient care trajectory looks like, limits one’s knowledge about the relationships that exist between departments and thus hampers efforts to develop holistic patient flow models. The most common approach used to catalogue patient care trajectories is through discussions with managers and care providers (Kotiadis, 2006; Pearson et al., 1995; Ferguson, 1993). More novel and automated approaches, involve using the information system protocol HL7 (Kopach-Konrad et al., 2007), medical record audits (Rossille et al., 2008), billing code audits (Dronzek, 2001), radio frequency identifiers (Rotondi et al., 1997), bar codes (Benneyan, 1997) and other patient tracking systems (Jensen, 2003). In this section Clinical Pathways (CP) Literature is reviewed and offered as an alternative method for describing patient care trajectories and conversely as a way to gain insight into the many relationships that exist between hospital departments.

3.1 Introduction to Clinical Pathways

CPs are multidisciplinary patient road maps (Giffin and Giffin, 1994) which can help eliminate the ambiguity of the patient care trajectory. “Most critical path efforts begin by documenting current practices and outcomes through chart review. This approach helps team members understand the complexities and dependent relations in the process before instituting change” (Coffey et al., 1992). CPs by definition are multidisciplinary and represent the flow of patients between care givers and across departments. “It can be thought of as a visualization of the patient care process” (Coffey et al., 2005). It involves bringing a multidisciplinary team with professional expertise to the development table to provide the knowledge and perspective needed to distinguish the entire care process (Ferguson, 1993; Pearson et al., 1995). Clearly this is the insight needed to design whole hospital models from a patient flow perspective.

As vast as the literature on CPs, are the definitions and terms used to describe it. A primary goal of CPs is to standardize patient care, but ironically there is nothing standard about its name, definition, or the procedures for implementing and auditing. This paper does not debate the merits of the various naming conventions or definitions but rather, examines how the scope of CPs can contribute in developing whole hospital patient flow models. For clarity the term Clinical Pathway is used as defined in (De Bleser et al., 2006).

De Bleser et al. (2006) searched the literature with the aim of identifying the key characteristics of a CP. To promote further discussion they offered the following as an initial definition. “A clinical pathway is a method for the patient-care management of a well-defined group of patients during a well-defined period of time. A clinical pathway explicitly states the goals and key elements of care based on Evidence Based Medicine (EBM) guidelines, best practice and patient expectations by facilitating the communication, coordination roles and sequencing the activities of the multidisciplinary care team, patients and their relatives; by documenting, monitoring and evaluating variances;

and by providing the necessary resources and outcomes. The aim of a clinical pathway is to improve the quality of care, reduce risks, increase patient satisfaction and increase the efficiency in the use of resources” (De Bleser et al., 2006).

From the definition of De Bleser et al. (2006) it is easy to see that there exists a relationship between CPs and modelling patient flows. This definition includes the statements, “well-defined group”, “well-defined period of time” and “explicitly stated goals.” From a patient flow and logistics point of view CPs define care milestones and timelines for a homogeneous group of patients. Knowing where patients are likely to go and when, is an essential component in developing multi-department models.

A quick review of CP literature reveals that the majority of the research debates the merits of CPs, shares the varied success and failures of CP case studies, and finally, describes how to develop, implement and measure CPs. This paper looks predominately at those articles which discuss how to develop CPs. The method used to identify relevant literature started from a review of development literature completed by Harkleroad et al. (2000). This paper identified and reviewed nine approaches to CPs development. These nine papers are the basis for the literature search which considered papers that cited one of these nine papers. Those papers that directly address or add to development methodologies are reviewed in detail. The following subsection discusses the extent of CPs scopes.

3.2 Clinical Pathways Scopes

Coffey et al. (1992) defines the scope of a CP to be “the range of application, or period of care, for which the critical path is developed.” Pearson et al. (1995) adds that they “are multidisciplinary in their development and in the scope of their implementation.” “The scope of the clinical pathway may cover an entire episode of care, such as hospitalization, home care, or preoperative care, or it may cover a more comprehensive spectrum of care” (Ireton-Jones et al., 1997). The literature contains an almost endless list of case studies and applications in a wide variety of areas and for a variety of pa-

tient types. Typical examples include: inpatient surgical care, complete episodes of care, specialized applications (ambulatory clinics) and life and health management (chronic conditions) (Coffey et al., 1992). “Adapted from other fields such as engineering, pathways in health care were used initially to simplify documentation and to reduce variation in nursing care. Economic pressures have led hospitals to expand the scope of pathways to include the entire treatment process for selected patient groups” (Muluk et al., 1997). By delineating the processes of care for a typical patient, pathways theoretically allow hospitals to better predict the costs associated with a particular patient subset” (Muluk et al., 1997).

Although CPs are arguably comprehensive in their scope (multidisciplinary and inclusive of all relevant departments) for a single patient type, they fail to consider how other patients competing for the same resources are affected. In contrast to the modellers considering all patient types within one department, CPs researchers consider all relevant departments but only one patient type. Furthermore, “critical pathways address processes for the ‘ideal’ patient and in some cases do not address issues for the majority of patients who enter the path” (Every et al., 2000).

From the literature it is unclear if patients on CPs are achieving higher throughput because of better organized care or because these patients simply have a higher priority (These may not be mutually exclusive). Clearly, if CP patients consume fewer resources as a result of the CP, there are benefits (more remaining resources) for the other patients. A similar argument in (Pearson et al., 2001) states, “If healthier patients are selected for treatment on a critical pathway, improvements in efficiency or outcome may reflect this clinical ‘cherry picking’ rather than the effect of pathway management.” With respect to whole hospital patient flow modelling this is significant as, in addition to interdepartmental relationships, one must also account for the interrelatedness of patients.

3.3 Pathway optimization

While reviewing the literature it became apparent that CPs used in health care have evolved away from the rigors of the critical pathways developed and used in other industries. This contrast is discussed in this subsection and is meant to convey the fact that CPs have gained considerable popularity even without substantial attention paid to pathway improvement.

“A critical path is an optimal sequencing and timing of interventions by physicians, nurses, and other staff for a particular diagnosis or procedure, designed to minimize delays and resource utilization and to maximize the quality of care” (Coffey et al., 1992). This definition from a frequently cited paper reads like a combinatorial optimization problem with variables (sequences and timing of interventions) and an objective function (minimize delays and resource utilization and to maximize the quality of care). Comparing this definition to that of De Bleser et al. (2006) 24 years later, gives the impression that the optimization component of CP has been since replaced by “documentation and descriptions of best practices.”

In a review of CPs by Pearson et al. (1995) it is stated that “In general, efforts to develop critical pathways in health care have not incorporated the formal techniques used by industrial predecessors to identify the true ‘critical’ pathway in any care process.” Instead Pearson et al. (1995) state that in the context of medical care the goals are; (1) to select “best practice”, (2) to define standards for the expected duration of hospital stay and for the use of tests and treatments (3) to exam the interrelations among the different steps in the care process to find ways to coordinate (4) to provide a common “game plan”, (5) to provide a framework for collecting data, (6) to decreasing nursing and physician documentation burdens and (7) to improve patient satisfaction through education.

Process improvement during the development stage has also received less attention. Of nine articles describing the development of CP reviewed in (Harkleroad et al., 2000) only one included a step to investigate related process problems. Furthermore, this single article states that “clinical path-

ways help with performance problems but do little about process problems other than identify them” (Gorden, 1995). Every et al. (2000) add that “pathways can serve as a screening test for inefficient care.”

In place of optimizing the care path, many authors suggest using variance data for continuous quality improvement projects. “Variances are deviations or ‘detours’ from the critical path. They may be positive or negative, avoidable or unavoidable” (Coffey et al., 1992). They are most often recorded on the CP documentation by selecting from pre-defined items. Reviewing this variance data and consequently changing the CP is a form of continuous process improvement (Coffey et al., 1992; Giffin and Giffin, 1994; Pearson et al., 1995; Ibarra et al., 1996; Gorden, 1995). It is unclear if this information is used to improve the care delivery or simply to realign the CP documentation with practice.

Although CP development has evolved away from the rigorousness of its industrial predecessor its contribution to improving health care should not be overlooked. “Efficiency and consistency are enhanced through identification of expected outcomes and health-care provider interventions. When outcomes and interventions are identified on a pathway, expectations are made clear to all health-care providers and to the patient” (Ibarra et al., 1996). CPs “translated into more consistent care delivery and more satisfied patients” (Greenfield, 1995). “In summary, clinical pathway development is a promising and widely used approach to the problem of integrating the clinical quality improvement and resource management efforts. Although controlled data regarding its effectiveness are limited, available information suggests that clinical pathways can reduce resource use while maintaining or improving clinical quality” (Ibarra et al., 1996).

3.4 Discussion

Once developed, CPs provide many conveniences for modellers. First CPs describe how patients interact within the multitude of departments in their care trajectory. Secondly as “a mechanism to coordinate care and to reduce fragmentation” (Panella et al., 2003) CPs can help to ensure that less complex organizational or protocol issues are addressed before beginning to develop quantitative models. Finally CPs reduce process variability which can greatly reduce the complexity for modelling hospital departments.

Conversely, operational research modellers can aid in the development of CPs. Employing operational research techniques during the development of CPs can help address deficiencies as discussed in the preceding section. These techniques can help restore CPs to the rigors of industry’s critical pathways by ensuring redesigned patient care trajectories are efficiently coordinated. Operational research can help to ensure that improvements in care for CPs patients (i.e. dedicated capacity) do not happen at the expense of the other patients. Further to this point Operational research can be used to balance the competing nature of multiple CPs existing within a single department.

4 Conclusion

The purpose of this paper is to highlight the extent to which operational research models account for interdepartmental relationships of hospital and to be a reference paper for researchers developing quantitative models of large portions of a hospital. Furthermore, CPs literature is reviewed and offered as a mechanism for determining department-to-department interactions and patient care trajectories. The specific conclusions from surveying these two distinct areas are discussed at the end of sections 2 and 3 respectively. On a more general level we find that researchers often take an atomistic view of hospitals, confine model scopes to a single department and overlook the complex relationships that exist in health care. We offer that this approach is in response to two adverse but

common characteristics of health care. The first, is the complexity and variability that is inherent in health care and the second is the absence of standard patient care trajectories. In this final section we explain these challenges in a bit more detail and discuss possibilities to overcome them.

The complexity and variability that is inherent in health care is in a way a double edged sword. On one hand its existence makes hospitals an ideal environment for applying operational research methods. On the other hand it either greatly limits the scope of models or forces modellers to take a more macro view. Either way, researchers lose a certain amount of perspective and perhaps draw conclusions on a model that does not incorporate the entire set of circumstances. To overcome this challenge requires modellers to be able to distinguish between those complicating factors that have the greatest influence and those factors which are simply attributes. This of course is more of an art than a science and depends greatly on how intimately one understands the system. To limit the amount of variability one has to cope with in a model, time should initially be spent on eliminating the variability that is caused by the system itself. This can often be achieved through good protocols or work practices and a clear understanding of the patient care trajectories.

The absence of standard patient care trajectories is as much a problem for management as it is a frustration for patients. Patients are often the one factor linking one department with another. Unfortunately when we do not know where patients are going, we can not fully understand how the departments interact. Overcoming this lack of information can be a very time consuming activity, as the knowledge often lies in piecemeal fashion with many different staff members. Effort to standardize care and define patient care trajectories are a large part of clinical pathways, focused factories and lean/six-sigma projects. When successful, such initiatives can create environments where patient flows and department interactions are more apparent. This of course allows operational researchers to spend more time developing models and less time sorting through and accounting for, many of the complexities of the process.

References

- Adan, I. and Vissers, J. (2002). Patient mix optimisation in hospital admission planning: a case study. *International Journal of Operations and Production Management*, 22(4):445–461.
- Akkerman, R. and Knip, M. (2004). Reallocation of Beds to Reduce Waiting Time for Cardiac Surgery. *Health Care Management Science*, 7(2):119–126.
- Altinel, I. and Ulas, E. (1996). Simulation modeling for emergency bed requirement planning. *Annals of Operations Research*, 67(1):183–210.
- Ashton, R., Hague, L., Brandreth, M., Worthington, D., and Cropper, S. (2005). A simulation-based study of a NHS Walk-in Centre. *Journal of the Operational Research Society*, 56(2):153–161.
- Bagust, A., Place, M., and Posnett, J. (1999). Dynamics of bed use in accommodating emergency admissions: stochastic simulation model. *British Medical Journal*, 319(7203):155–158.
- Bailey, N. (1952). A study of queues and appointment systems in hospital outpatient departments, with special reference to waiting times. *Journal of the Royal Statistical Society*, 14(2):185–99.
- Beland, F., Bergman, H., Lebel, P., Clarfield, A., Tousignant, P., Contandriopoulos, A., and Dallaire, L. (2006). A System of Integrated Care for Older Persons With Disabilities in Canada: Results From a Randomized Controlled Trial. *Journals of Gerontology Series A: Biological and Medical Sciences*, 61(4):367–373.
- Beliën, J. and Demeulemeester, E. (2007). Building cyclic master surgery schedules with leveled resulting bed occupancy. *European Journal of Operational Research*, 176(2):1185–1204.
- Beliën, J., Demeulemeester, E., and Cardoen, B. (2006). Visualizing the Demand for Various Re-

- sources as a Function of the Master Surgery Schedule: A Case Study. *Journal of Medical Systems*, 30(5):343–350.
- Benneyan, J. (1997). An introduction to using computer simulation in healthcare: patient wait case study. *Journal of the Society for Health Systems*, 5(3):1–15.
- Black, D. and Pearson, M. (2002). Average length of stay, delayed discharge, and hospital congestion a combination of medical and managerial skills is needed to solve the problem. *British Medical Journal (International ed.)*, 325(7365):610–611.
- Blake, J. (2005). Shooting arrows in the dark: the policies and practices of waitlist management in canada. *Clinical and investigative medicine*, 28(6):308–311.
- Blake, J. and Carter, M. (1997). Surgical process scheduling: a structured review. *J Soc Health Syst*, 5(3):17–30.
- Blake, J., Carter, M., and Richardson, S. (1996). An Analysis of Emergency Room Wait Time Issues via Computer Simulation. *INFOR*, 34:263–273.
- Blake, J. and Donald, J. (2002). Mount Sinai Hospital Uses Integer Programming to Allocate Operating Room Time. *Interfaces*, 32(2):63–73.
- Blasak, R., Armel, W., Starks, D., Hayduk, M., Center, R., and Skokie, I. (2003). The use of simulation to evaluate hospital operations between the emergency department and a medical telemetry unit. In *Proceedings of the 2003 Winter Simulation Conference*, volume 2.
- Blatchford, O. and Capewell, S. (1997). Emergency medical admissions: taking stock and planning for winter. *British Medical Journal*, 315(7119):1322.
- Bonvissuto, C. (1994). Avoiding unnecessary critical care costs. *Healthcare Financial Management*, 48(11):47–52.

- Bowers, J. and Mould, G. (2002). Concentration and the variability of orthopaedic demand. *Journal of the Operational Research Society*, 53:203–210.
- Bowers, J. and Mould, G. (2005). Ambulatory Care and Orthopaedic Capacity Planning. *Health Care Management Science*, 8(1):41–47.
- Brailsford, S., Lattimer, V., Tarnaras, P., and Turnbull, J. (2004). Emergency and on-demand health care: modelling a large complex system. *Journal of the Operational Research Society*, 55(1):34–42.
- Brasted, C. (2008). Ultrasound waiting lists: rational queue or extended capacity? *Health Care Management Science*, 11(2):196–207.
- Calichman, M. (2005). Creating an Optimal Operating Room Schedule. *AORN Journal*, 81(3):580–588.
- Capewell, S. (1996). The continuing rise in emergency admissions. *British Medical Journal*, 312(7037):991–992.
- Cardoen, B., Demeulemeester, E., and Beliën, J. (2008). Operating room planning and scheduling: List of references. Retrieved October 10, 2008, from <http://www.econ.kuleuven.be/public/ndbaa92/bibliography.pdf>.
- Carter, M. (2002). Diagnosis: Mismanagement of resources. *OR/MS Today*, 29(2):26–32.
- Carter, M. and Blake, J. (2004). Using simulation in an acute-care hospital: easier said than done. In Brandeau, M., Sainfort, F., and Pierskalla, W., editors, *Operations Research and Health Care: A Handbook of Methods and Applications*. Kluwer Academic Publishers, New York.
- Cayirli, T. and Veral, E. (2003). Outpatient Scheduling in Health Care: A Review of Literature. *Production and Operations Management*, 12(4):519–549.

- Cayirli, T., Veral, E., and Rosen, H. (2006). Designing appointment scheduling systems for ambulatory care services. *Health Care Management Science*, 9(1):47–58.
- Ceglowski, R., Churilov, L., and Wasserthiel, J. (2007). Combining data mining and discrete event simulation for a value-added view of a hospital emergency department. *The Journal of the Operational Research Society*, 58(2):246–254.
- Centeno, M., Albacete, C., Terzano, D., Carrillo, M., and Ogazon, T. (2000). A simulation study of the radiology department at JMH. In *Proceedings of the 2000 Winter Simulation Conference*, pages 1978–1984.
- Chick, S., SÁnchez, P. J., Ferrin, D., Morrice, D. J., Mahapatra, S., Koelling, C. P., Patvivatsiri, L., and Fraticelli, B. (2003). Pairing Emergency Severity Index-5-Level. In *Proceedings of the 2003 Winter Simulation Conference*.
- Cochran, J. and Bharti, A. (2006a). A multi-stage stochastic methodology for whole hospital bed planning under peak loading. *International Journal of Industrial and Systems Engineering*, 1(1):8–36.
- Cochran, J. and Bharti, A. (2006b). Stochastic bed balancing of an obstetrics hospital. *Health Care Management Science*, 9(1):31–45.
- Coffey, R., Richards, J., Remmert, C., LeRoy, S., Schoville, R., and Baldwin, P. (1992). An introduction to critical paths. *Quality Management in Health Care*, 1(1):45–54.
- Coffey, R., Richards, J., Remmert, C., LeRoy, S., Schoville, R., and Baldwin, P. (2005). An introduction to critical paths. *Quality Management in Health Care*, 14(1):46.
- Conforti, D., Guerriero, F., and Guido, R. (2007). Optimization models for radiotherapy patient scheduling. *4OR: A Quarterly Journal of Operations Research*, 6(3):263–278.

- Costa, A., Ridley, S., Shahani, A., Harper, P., De Senna, V., and Nielsen, M. (2003). Mathematical modelling and simulation for planning critical care capacity. *Anaesthesia*, 58(4):320.
- Cote, M. (2000). Understanding Patient Flow. *Decision Line*, 31:8–10.
- Criswell, M., Hasan, I., Kopach, R., Lambert, S., Lawley, M., McWilliams, D., Trupiano, G., and Varadarajan, N. (2007). Emergency department divert avoidance using petri nets. *Proceedings of the IEEE International Conference on System of Systems Engineering*. 1–6.
- Currie, C., Hoy, D., Tierney, A., Bryan-Jones, J., and Lapsley, I. (2003). HipMod: Development of a Multi-Agent Audit-Based Computer Simulation of Hip Fracture Care. *Health Informatics Journal*, 9(3):183.
- Dansky, K. and Miles, J. (1997). Patient satisfaction with ambulatory healthcare services: waiting times and filling time. *Hospital and health services administration*, 77:42–165.
- De Bleser, L., Depreitere, R., De Waele, K., Vanhaecht, K., Vlayen, J., and Sermeus, W. (2006). Defining pathways. *Journal of Nursing Management*, 14(7):553–563.
- de Bruin, A., Koole, G., and Visser, M. (2005). Bottleneck analysis of emergency cardiac in-patient flow in a university setting: an application of queueing theory. *Clinical & Investigative Medicine*, 28(6):316–7.
- Dean, B., Allan, E., Barber, N., and Barker, K. (1995). Comparison of medication errors in an American and a British hospital. *American Journal of Health-System Pharmacy*, 52(22):2543.
- Dean, B., van Ackere, A., Gallivan, S., and Barber, N. (1999). When should pharmacists visit their wards? An application of simulation to planning hospital pharmacy services. *Health Care Management Science*, 2(1):35–42.

- Derlet, R. and Richards, J. (2000). Overcrowding in the nation's emergency departments: Complex causes and disturbing effects. *Annals of emergency medicine*, 35(1):63–68.
- Dexter, F. (2009). Bibliography of Operating Room Management Articles. Retrieved October 10, 2008 from <http://www.franklindexter.net>.
- Dexter, F., Blake, J., Penning, D., Sloan, B., Chung, P., and Lubarsky, D. (2002). Use of linear programming to estimate impact of changes in a hospital's operating room time allocation on perioperative variable costs. *Anesthesiology*, 96(3):718–724.
- Dexter, F. and Lubarsky, D. (2004). Using length of stay data from a hospital to evaluate whether limiting elective surgery at the hospital is an inappropriate decision. *Journal of Clinical Anesthesia*, 16(6):421–425.
- Dexter, F., Macario, A., and Traub, R. (2000). Enterprise-Wide Patient Scheduling Information Systems to Coordinate Surgical Clinic and Operating Room Scheduling Can Impair Operating Room Efficiency. *Anesthesia & Analgesia*, 91(3):617–626.
- Dimakou, S., Parkin, D., Devlin, N., and Appleby, J. (2008). Identifying the impact of government targets on waiting times in the NHS . *Health Care Management Science (to appear)*.
- Dronzek, R. (2001). Improving critical care Simulation is used to improve a hospital's emergency department. *IIE Solutions*, 33(11):42–47.
- Drummond, A. (2002). No room at the inn: overcrowding in ontario's emergency departments. *Canadian Journal of Emergency Medicine*, 4(2):91–7.
- Epstein, R. and Dexter, F. (2000). Economic Analysis of Linking Operating Room Scheduling and Hospital Material Management Information Systems for Just-in-Time Inventory Control. *Anesthesia & Analgesia*, 91(2):337–343.

- Everett, J. (2002). A Decision Support Simulation Model for the Management of an Elective Surgery Waiting System. *Health Care Management Science*, 5(2):89–95.
- Every, N. R., Hochman, J., Becker, R., Kopecky, S., and Cannon, C. P. (2000). Critical Pathways : A Review. *Circulation*, 101(4):461–465.
- Ferguson, L. (1993). Steps to developing a critical pathway. *Nursing Administration Quarterly*, 17(3):58–62.
- Fletcher, A. and Worthington, D. (2007). What is a ‘generic’ hospital model? Retrieved October 13, 2008, from <http://eprints.lancs.ac.uk/7051/1/004583.pdf>.
- Giffin, M. and Giffin, R. (1994). Critical pathways produce tangible results. *Health Care Strategic Management*, 12(7):1–17.
- Gorden, M. (1995). Steps to pathway development. *The Journal of burn care & rehabilitation*, 16(2):197–202.
- Greenfield, E. (1995). Critical pathways: What they are and what they are not. *Journal of Burn Care and Rehabilitation*, 16(2):196–197.
- Griffiths, J., Price-Lloyd, N., Smithies, M., and Williams, J. (2005). Modelling the requirement for supplementary nurses in an intensive care unit. *Journal of the Operational Research Society*, 56(2):126–133.
- Gross, M. (2004). Wait times: the appropriateness of the methodology and how they affect patients. *Canadian Journal of Surgery*, 47(3):167–169.
- Guinet, A. and Chaabane, S. (2003). Operating theatre planning. *International Journal of Production Economics*, 85(1):69–81.

- Hall, R. (2006). *Patient Flow: Reducing Delay in Healthcare Delivery*. Springer, New York, first edition.
- Hanratty, B. and Robinson, M. (1999). Coping with winter bed crises new surveillance systems might help. *British Medical Journal*, 319(7224):1511–1512.
- Harkleroad, A., Schirf, D., Volpe, J., and Holm, M. (2000). Critical pathway development: an integrative literature review. *American Journal of Occupational Therapy*, 54(2):148–54.
- Harper, P. and Shahani, A. (2002). Modelling for the planning and management of bed capacities in hospitals. *Journal of the Operational Research Society*, 53:11–1.
- Hopp, W. and Spearman, M. (2001). *Factory physics: foundations of manufacturing management*. McGraw-Hill, Boston.
- Huang, X. (1994). Patient attitude towards waiting in an outpatient clinic and its applications. *Health Services Management Research*, 7(1):2–8.
- Ibarra, V., Titler, M., and Reiter, R. (1996). Issues in the development and implementation of clinical pathways. *AACN Clinical Issues*, 7(3):436–47.
- IHI (2003). Optimizing patient flow: Moving patients smoothly through acute care settings. Retrieved June 23, 2008 from <http://www.ihl.org/IHI/Results/WhitePapers>.
- Ireton-Jones, C., Orr, M., and Hennessy, K. (1997). Clinical pathways in home nutrition support. *Journal of the American Dietetic Association*, 97(9):1003–1007.
- Jebali, A., Hadj Alouane, A., and Ladet, P. (2006). Operating rooms scheduling. *International Journal of Production Economics*, 99(1-2):52–62.

- Jensen, J. (2003). Going with the flow. Tracking system helps midwest hospital streamline patient flow and lower emergency room divert rate. *Health Management Technology*, 24(12):43–45.
- Jiang, L. and Giachetti, R. (2008). A queueing network model to analyze the impact of parallelization of care on patient cycle time. *Health Care Management Science*, 11(3):248–261.
- Johansson, L. (1997). Decentralisation from acute to home care settings in Sweden. *Health policy*, 41:131–143.
- Jun, J., Jacobson, S., and Swisher, J. (1999). Application of Discrete-Event Simulation in Health Care Clinics: A Survey. *Journal of the Operational Research Society*, 50(2):109–123.
- Kim, S. and Horowitz, I. (2002). Scheduling hospital services: the efficacy of elective-surgery quotas. *Omega*, 30(5):335–346.
- Kim, S., Horowitz, I., Young, K., and Buckley, T. (1999). Analysis of capacity management of the intensive care unit in a hospital. *European Journal of Operational Research*, 115(1):36–46.
- Kim, S., Horowitz, I., Young, K., and Buckley, T. (2000). Flexible bed allocation and performance in the intensive care unit. *Journal of Operations Management*, 18(4):427–43.
- Koizumi, N., Kuno, E., and Smith, T. (2005). Modeling Patient Flows Using a Queuing Network with Blocking. *Health Care Management Science*, 8(1):49–60.
- Kokangul, A. (2008). A combination of deterministic and stochastic approaches to optimize bed capacity in a hospital unit. *Computer Methods and Programs in Biomedicine*, 90(1):56–65.
- Kolker, A. (2008). Process Modeling of ICU Patient Flow: Effect of Daily Load Leveling of Elective Surgeries on ICU Diversion. *Journal of Medical Systems*, pages 1–14.

- Kommer, G. (2002). A Waiting List Model for Residential Care for the Mentally Disabled in the Netherlands. *Health Care Management Science*, 5(4):285–290.
- Kopach-Konrad, R., Lawley, M., Criswell, M., Hasan, I., Chakraborty, S., Pekny, J., and Doebbeling, B. (2007). Applying Systems Engineering Principles in Improving Health Care Delivery. *Journal of General Internal Medicine*, 22:431–437.
- Kotiadis, K. (2006). Extracting a conceptual model for a complex integrated system in healthcare. In Garnett, J., Brailsford, S., Robinson, S., and Taylor, S., editors, *Proceedings of the Third Operational Research Society Simulation Workshop*, pages 235–245. The Operational Research Society.
- Kwak, N., Kuzdrall, P., and Schmitz, H. (1976). The GPSS simulation of scheduling policies for surgical patients. *Management Science*, 22(9):982–9.
- Lane, D., Monefeldt, C., and Rosenhead, J. (2000). Looking in the Wrong Place for Healthcare Improvements: A System Dynamics Study of an Accident and Emergency Department. *Journal of the Operational Research Society*, 51(5):518–531.
- Lovejoy, W. and Li, Y. (2002). Hospital Operating Room Capacity Expansion. *Management Science*, 48(11):1369.
- Lowery, J. and Martin, J. (1989). Evaluation of an advance surgical scheduling system. *Journal of Medical Systems*, 13(1):11–23.
- Martin, S. and Smith, P. (1999). Rationing by waiting lists: an empirical investigation. *Journal of Public Economics*, 71(1):141–164.
- Masursky, D., Dexter, F., O’Leary, C., Applegeet, C., and Nussmeier, N. (2008). Long-Term Forecasting of Anesthesia Workload in Operating Rooms from Changes in a Hospital’s Local Population Can Be Inaccurate. *Anesthesia & Analgesia*, 106(4):1223.

- Matta, M. and Patterson, S. (2007). Evaluating multiple performance measures across several dimensions at a multi-facility outpatient center. *Health Care Management Science*, 10(2):173–194.
- Mayhew, L. (2008). On the effectiveness of care co-ordination services aimed at preventing hospital admissions and emergency attendances. *Health Care Management Science (to appear)*.
- McGowan, J., Truwit, J., Cipriano, P., Howell, R., VanBree, M., Garson, A., and Hanks, J. (2007). Operating Room Efficiency and Hospital Capacity: Factors Affecting Operating Room Use During Maximum Hospital Census. *Journal of the American College of Surgeons*, 204(5):865–871.
- McManus, M., Long, M., Cooper, A., Mandell, J., Berwick, D., Pagano, M., and Litvak, E. (2003). Variability in surgical caseload and access to intensive care services. *Anesthesiology*, 98(6):1491–6.
- Muluk, S., Painter, L., Sile, S., Rhee, R., Makaroun, M., Steed, D., and Webster, M. (1997). Utility of clinical pathway and prospective case management to achieve cost and hospital stay reduction for aortic aneurysm surgery at a tertiary care hospital. *Journal of Vascular Surgery*, 25(1):84–93.
- Nguyen, J., Six, P., Antonioli, D., Glemain, P., Potel, G., Lombrail, P., and Le Beux, P. (2005). A simple method to optimize hospital beds capacity. *International Journal of Medical Informatics*, 74(1):39–49.
- Nguyen, J., Six, P., Parisot, R., Antonioli, D., Nicolas, F., and Lombrail, P. (2003). A universal method for determining intensive care unit bed requirements. *Intensive Care Medicine*, 29(5):849–852.
- O’Kane, P. (1981). A Simulation Model of a Diagnostic Radiology Department. *European Journal of Operational Research*, 6:38–45.

- Oudhoff, J., Timmermans, D., Rietberg, M., Knol, D., and Van der Wal, G. (2007). The acceptability of waiting times for elective general surgery and the appropriateness of prioritising patients. *BMC Health Services Research*, 7(1):32.
- Panella, M., Marchisio, S., and Di Stanislao, F. (2003). Reducing clinical variations with clinical pathways: do pathways work? *International Journal for Quality in Health Care*, 15(6):509.
- Pearson, S., Goulart-Fisher, D., and Lee, T. (1995). Critical pathways as a strategy for improving care: Problems and potential. *Annals of Internal Medicine*, 123(12):941–948.
- Pearson, S., Kleeffeld, S., Soukop, J., Cook, E., and Lee, T. (2001). Critical pathways intervention to reduce length of hospital stay. *The American Journal of Medicine*, 110(3):175–180.
- Pham, D. and Klinkert, A. (2008). Surgical case scheduling as a generalized job shop scheduling problem. *European Journal of Operational Research*, 185(3):1011–1025.
- Pitt, D., Noseworthy, T., Guilbert, J., and Williams, J. (2003). Waiting lists: management, legalities and ethics. *Canadian Journal of Surgery*, 46(3):170–175.
- Proudlove, N., Black, S., and Fletcher, A. (2007). OR and the challenge to improve the NHS: modelling for insight and improvement in in-patient flows. *Journal of the Operational Research Society*, 58(2):145–158.
- Ramis, F., Palma, J., and Baesler, F. (2001). The use of simulation for process improvement at an ambulatory surgery center. In *Proceedings of the 2001 Winter Simulation Conference*, pages 1401–1404.
- Renwick, M., Gillett, S., and Liu, Z. (1992). Long-stay older patients in acute hospitals: are they bed blockers? *Australian health review*, 15(3):284–98.

- Rossille, D., Cuggia, M., Arnault, A., Bouget, J., and Le Beux, P. (2008). Managing an emergency department by analysing HIS medical data: a focus on elderly patient clinical pathways. *Health Care Management Science*, 11(2):139–146.
- Rotondi, A., Brindis, C., Cantees, K., DeRiso, B., Ilkin, H., Palmer, J., Gunnerson, H., and Watkins, W. (1997). Benchmarking the perioperative process. I. Patient routing systems: a method for continual improvement of patient flow and resource utilization. *Journal of Clinical Anesthesia*, 9(2):159–69.
- Rubin, S. and Davies, G. (1975). Bed blocking by elderly patients in general-hospital wards. *Age and Ageing*, 4(3):142–147.
- Samaha, S., Armel, W., and Starks, D. (2003). The use of simulation to reduce the length of stay in an emergency department. In *Proceedings of the 2003 Winter Simulation Conference*, volume 2.
- Santibanez, P., Begen, M., and Atkins, D. (2005). Managing surgical waitlists for a british columbia health authority. Retrieved October 10, 2008, from <http://www.chcm.ubc.ca/docs/Managing-Surgical-Waitlists-British-Columbia-Health-Authority.pdf>.
- Santibáñez, P., Begen, M., and Atkins, D. (2007). Surgical block scheduling in a system of hospitals: an application to resource and wait list management in a British Columbia health authority. *Health Care Management Science*, 10(3):269–282.
- Sier, D., Tobin, P., and McGurk, C. (1997). Scheduling Surgical Procedures. *Journal of the Operational Research Society*, 48(9):884–891.
- Skinner, W. (1985). *Manufacturing: The Formidable Competitive Weapon*. John Wiley & Sons Inc, New York.

- Sobolev, B., Harel, D., Vasilakis, C., and Levy, A. (2008). Using the statecharts paradigm for simulation of patient flow in surgical care. *Health Care Management Science*, 11(1):79–86.
- Sokal, S., Craft, D., Chang, Y., Sandberg, W., and Berger, D. (2006). Maximizing Operating Room and Recovery Room Capacity in an Era of Constrained Resources. *Archives of Surgery*, 141(4):389.
- Takakuwa, S. and Shiozaki, H. (2004). Functional analysis for operating emergency department of a general hospital. In *Proceedings of the 2004 Winter simulation Conference*, pages 2003–2011.
- Taylor, K. and Lane, D. (1998). Simulation applied to health services: opportunities for applying the system dynamics approach. *Journal of Health Services Research & Policy*, 3(4):226–32.
- Testi, A. and Tanfani, E. (2008). Tactical and operational decisions for operating room planning: Efficiency and welfare implications. *Health Care Management Science (to appear)*.
- Testi, A., Tanfani, E., and Torre, G. (2007). A three-phase approach for operating theatre schedules. *Health Care Management Science*, 10(2):163–172.
- Utley, M., Gallivan, S., Davis, K., Daniel, P., Reeves, P., and Worrall, J. (2003). Estimating bed requirements for an intermediate care facility. *European Journal of Operational Research*, 150(1):92–100.
- van der Meer, R., Rymaszewski, L., Findlay, H., and Curran, J. (2005). Using OR to support the development of an integrated musculo-skeletal service. *Journal of the Operational Research Society*, 56(2):162–172.
- van Dijk, N. (2000). On hybrid combination of queueing and simulation. In *Proceedings of the 2000 Winter simulation Conference*, pages 147–150.

- van Dijk, N. M. and van der Sluis, E. (2008). Practical optimization by OR and simulation. *Simulation Modelling Practice and Theory*, 16(8):1113 – 1122. EUROSIM 2007.
- van Houdenhoven, M., van Oostrum, J., Hans, E., Wullink, G., and Kazemier, G. (2007). Improving Operating Room Efficiency by Applying Bin-Packing and Portfolio Techniques to Surgical Case Scheduling. *Anesthesia & Analgesia*, 105(3):707.
- van Houdenhoven, M., van Oostrum, J., Wullink, G., Hans, E., Hurink, J., Bakker, J., and Kazemier, G. (2008). Fewer intensive care unit refusals and a higher capacity utilization by using a cyclic surgical case schedule. *Journal of Critical Care*, 23(2):222–226.
- van Oostrum, J., van Houdenhoven, M., Hurink, J., Hans, E., Wullink, G., and Kazemier, G. (2008). A master surgical scheduling approach for cyclic scheduling in operating room departments. *OR Spectrum*, 30(2):355–374.
- VanBerkel, P. and Blake, J. (2007). A comprehensive simulation for wait time reduction and capacity planning applied in general surgery. *Health Care Management Science*, 10(4):373–385.
- Vasilakis, C. and Marshall, A. (2005). Modelling nationwide hospital length of stay: opening the black box. *Journal of the Operational Research Society*, 56(7):862–869.
- Villa, S., Barbieri, M., and Lega, F. (2008). Restructuring patient flow logistics around patient care needs: implications and practicalities from three critical cases. *Health Care Management Science (to appear)*.
- Vissers, J. (1998). Patient flow-based allocation of inpatient resources: A case study. *European Journal of Operational Research*, 105(2):356–370.
- Vissers, J. and Beech, R. (2005). *Health Operations Management: Patient Flow Logistics in Health Care*. Routledge, Oxon.

- Wachtel, R. and Dexter, F. (2008). Tactical Increases in Operating Room Block Time for Capacity Planning Should Not Be Based on Utilization. *Anesthesia & Analgesia*, 106(1):215.
- Walley, P., Silvester, K., and Steyn, R. (2006). Managing variation in demand: lessons from the UK National Health Service. *Journal of Healthcare Management*, 51(5):309–20.
- Wartman, S., Morlock, L., Malitz, F., and Palm, E. (1983). Patient understanding and satisfaction as predictors of compliance. *Medical care*, 21(9):886–91.
- Wong, C., Geiger, G., Derman, Y., Busby, C., and Carter, M. (2003). Redesigning the medication ordering, dispensing, and administration process in an acute care academic health sciences centre. In *Proceedings of the 2003 Winter Simulation Conference*.
- Worthington, D. (1991). Hospital waiting list management models. *Journal of the Operational Research Society*, 42(10):833–843.
- Wright, M. (1987). The application of a surgical bed simulation model. *European Journal of Operational Research*, 32(1):26–32.