

## Leaving a mark on healthcare delivery with operations analysis

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In the Dutch context we see similar problems as outlined in Linda Green's commentary and, due in part to the redesign of the healthcare financing structure in the Netherlands, we have also seen a tremendous increase in the demand for operations analysis. The major redesign of the financial structure is described below, but for now, it is sufficient to state that its principal purpose is to achieve better value for the money spent on healthcare. Achieving more value for money is certainly an area where operations analysis can play a leading role. As a result, the demand for both our research capacity and recent graduates has been increasing. Furthermore, since healthcare providers are truly engaged, implementations of our results and recommendations have likewise increased. In this paper, we discuss recent projects to build on Linda Green's commentary and to argue *how to* apply operations analysis in healthcare in a scientifically and practically relevant way.

In several short years, our research group has gone from asking ourselves: "How do we find healthcare providers to partner with?" to "How do we keep up with all the partners' requests?" As have many researchers and research groups, we have developed many strong and fruitful partnerships but have also squandered some opportunities. To try and maximize the former, our approach to collaborating with healthcare providers has evolved over time and is now proving effective in finding and isolating scientifically interesting problems which, when solved, have a significant positive impact on healthcare providers operations. Our goal as a research group is to improve healthcare providers operations, as well as to further develop the science and techniques of operations research.

At many conferences, it is common for the following questions to be discussed (both formally and informally): "How do we get healthcare providers engaged in our research?", "How do we get the healthcare providers to implement our results?", "How do we test our results across multiple hospitals?" Furthermore, many review papers question whether the promised contribution of applying operations analysis is being achieved in healthcare (Lagergren 1998), since reporting implementation results is rarely done in journal articles (Katsaliaki & Mustafee 2011). It follows that there is a need to discuss how best to work with healthcare providers.

Given this need and our recent progress in this regard, the focus of this commentary is to share the lessons we have learned while building a network of collaborating healthcare providers across the Netherlands. We now partner with healthcare providers of various types, including academic hospitals, general hospitals, and specialty hospitals, rehabilitation centres, government, and information

technology companies. Aside from the research done by PhD students and staff, our research group supervises countless graduation projects completed by MSc and BSc students embedded in these organizations. Some 20% of the MSc students remain to work in the healthcare domain, which continuously strengthens our network.

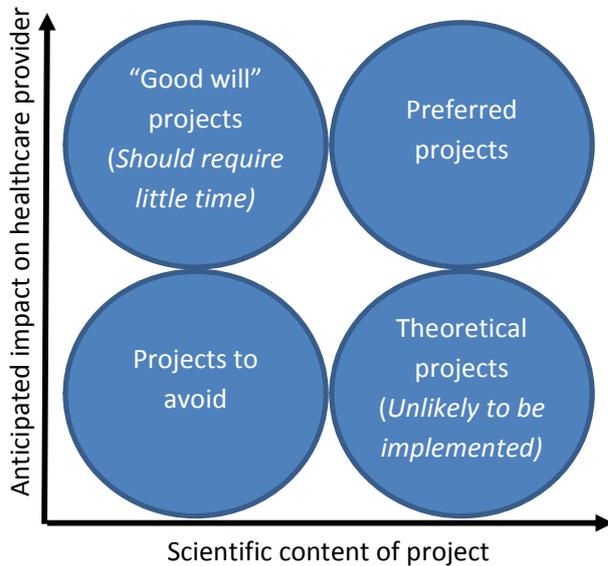
We begin this commentary by outlining our general approach which is, for the most part, common to all of our partnerships. Then, we explain intricacies of the Dutch healthcare system and how it has evolved to create a hospitable environment for operations analysis. We then discuss specific projects that have addressed problems related to the three “big problem areas” outlined by Linda Green. Whereas Linda Green reports on “what should be done”, the focus of this paper will be on “what is being done”, with particular attention paid to implementation and its impact on hospital operations.

### **General approach**

*Getting healthcare providers commitment:* We ask healthcare providers to hire (or support financially) our MSc and PhD students for 2-3 days per week and often we match their funding. This serves two purposes; firstly, it makes them invested in the collaboration, and secondly, it helps eliminate barriers for our students. For example, as employees, students have easier access to data, become part of the team and begin to build collaborative relationships. Furthermore, as employees our students have a “company” email address, become listed in the directory and have access to staff calendars. All of these seemingly minor things, when combined, greatly increase student exposure and make students and hospital staff more accessible to each other. Many healthcare providers may want collaboration without a financial obligation, at least at first. We often take on these partnerships but still insist on a 0 hour contract (i.e. no money is exchanged but the student is still an employee). We are upfront regarding this setup and expectations, but also about our research mandate. We want to help improve healthcare providers operations, but we also want to solve problems that both apply and build on existing literature. When this is clear to both parties, selecting a project can be done in a more seamless manner.

*Project selection:* We ask healthcare providers to propose problems of interest to them, but collaboratively we choose which to focus on. In general we select projects according to the scientific novelty, anticipated impact on healthcare providers operations, value for other healthcare providers, and time requirements. Of course, if we deem a project to be scientifically outstanding, we almost always take it on, and preference is given to those projects which we anticipate to also have a high impact for the healthcare provider. However, we also often consider shorter projects which focus more on implementation and which will have a large positive impact on the healthcare provider. In particular we take on these projects when they can serve as student graduation projects. For example, developing a value stream map may not lead to a scientific publication but will likely help to improve a healthcare provider’s processes. We choose to do this because it may lead to positive exposure via articles in professional magazines; it builds “good will” with staff and managers and often leads to other, more scientifically interesting problems. We will also consider spending time on projects with less scientific content if we feel there is potential for more scientifically relevant projects to follow. Projects with little scientific relevance that require much time are often not completed by our research group; however

caution should be used in saying “no” too often. If managers and healthcare professionals hear “no” multiple times they may simply stop asking. Our project selection approach is illustrated in Figure 1.



**FIGURE 1:** Our project selection approach

Some of our projects are initiated by practitioners who participate in our healthcare operations management courses. In addition to operations management theory, participants must work on an actual problem from their own practice.

*Research team:* The primary researcher is typically a PhD student supported by professors from appropriate research groups. The supporting professors are assigned after the project is selected and based on the expertise needed. For example, depending on the problem, professors from stochastic operations research, mathematical programming, industrial engineering, and/or health technology may be involved. From the healthcare provider, it is important to include a team member who is at the upper echelons of management; it is easier for a senior manager to find someone at the operational level to fill in details than to have someone at the operational level find a senior manager to support the cause. Including a team member who is involved in the concerned clinical area (e.g. a physician, nurse or pharmacist) is also essential for understanding the clinical decision making process and how interventions impact patients and clinical practices. If the healthcare provider has in-house Industrial Engineers (or quality improvement team members), we try to involve them in the project as well. These professionals typically know how to access data, understand the organization’s history, and often have more time to commit to the project than senior management team members. Furthermore, they can provide the continuity necessary to ensure the results are sustained overtime. Where possible, we involve students in preliminary steps related to information gathering, process mapping and initial analysis.

*Implementation:* In our research, we aim to provide both general results and results specific to a given situation or case study. For example, a general result states that the benefits of pooling are small when resources are highly utilized, whereas a specific result states the relative benefit for a variety of utilization levels in a given department. Depending on the project, the general result may guide senior management strategy whereas the specific results may influence operational decisions. For successful implementation, one must consider the medium by which such results are given to the healthcare provider. For example, operational policies which guide decision making are easier to implement than decision support tools. However, decision support tools may be more robust and better able to cope with future process changes. Where possible, we frame our results in terms of policies (e.g. when the stock level falls below  $s$ , order up to  $S$  new products). When decision support software is necessary we either build it in-house, or partner with an information technology company. In the past, we have developed decision support systems in partnership with Information Builders ([www.informationbuilders.com](http://www.informationbuilders.com)) and ORTEC ([www.ortec.com](http://www.ortec.com)).

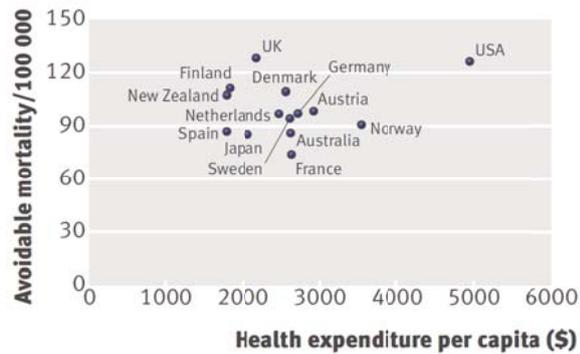
*Dissemination:* When we have success in terms of implemented results or scientific publications we announce them over a variety of mediums. We hold quarterly meetings at partner institutions where we jointly update our partners on recent successes and future opportunities. We use social media, including LinkedIn and Twitter (@choir\_unitwente). We maintain a website for our group and also an online bibliography called ORchestra ([www.utwente.nl/choir/en/orchestra/](http://www.utwente.nl/choir/en/orchestra/); see Hulshof et al. 2011). Our research group meets twice a month for 2 hours to present new opportunities and discuss ongoing research; healthcare professionals are invited and often attend. We attend national and international conferences and encourage our PhD students to spend between 2 and 6 months on an international research visit with leading researchers in the field. In the past we have visited the Centre for Health Care Management (University of British Columbia), Centre for Research in Healthcare Engineering (University of Toronto) and Centre for Industry and Innovation Studies (University of Western Sydney). To celebrate major accomplishments, such as PhD graduations, we organize day-long symposiums and invite leading researchers to give plenary talks. The most recent symposium was attended by over 150 people and represented an approximately equal mix of academics and healthcare professionals. Finally, we support spin-off companies which result from successful projects ([www.logiqol.nl](http://www.logiqol.nl)).

### **Some important features of the Dutch healthcare system**

Recent changes in the financing structure of the Dutch healthcare system have created a climate conducive to operations analyses. These changes are discussed in this section to provide context for the environment in which we are working. Although this may be different from other countries, it is worth exploring since it has acted as a catalyst for making operations analysis common place in many Dutch hospitals.

When describing the Dutch healthcare system we distinguish between the pre-2006 era and post-2006 era, during which dramatic reforms were introduced and implemented. During the pre-2006 era the quality of care was found to be high when compared to countries such as Germany and the United

States, and in general was accessible and equitably distributed (Westert et al. 2006). That said, the costs were high and the return on investment was low, as compared to similar countries (Westert et al. 2009). This is illustrated in Figure 2 where avoidable mortalities are compared to health expenditures per capita. The Netherlands' placement in the middle of the pack illustrates that costs-for-care received were relatively high.



**FIGURE 2:** Avoidable mortalities in relation to health expenditures per capita (from Westert et al. 2009).

The dramatic reforms implemented in 2006 were further motivated by a 1987 review of the healthcare system, which found it to lack efficiency and awareness of costs both among consumers and providers (Dekker 1987). The report also found “that rigid governmental regulation inhibited flexible organization and thwarted innovation” (Westert et al. 2009). With reports questioning the efficiency of the healthcare system and the return on investments for Dutch citizens, the government went about reinventing the country’s Health Insurance Act.

In 2006 the new Health Insurance Act was passed. The underlying philosophy of the act is to have health insurance companies advocate on behalf of their enrollees in terms of both cost and quality of care. Essentially, health insurance companies represent a collective of Dutch citizens with larger buying power and more clout to demand higher quality of care. When citizens are unhappy with their healthcare provider they can ask their insurance company to intervene. If citizens are unhappy with the insurance company, they can switch insurance companies. This philosophy provides incentives to insurers to be prudent purchasers of healthcare (value for money) and healthcare providers are incentivized by insurance companies to deliver high quality care at low costs (Westert et al. 2009).

Like many good philosophies the devil is in the details, and to implement the reforms without adverse consequences a number of key elements were needed. These elements included (Westert et al. 2009):

- All adults are obligated to buy Basic health insurance but can choose any insurer
- Children (under 18 years) are insured for free
- Low income groups receive financial compensation
- All insurers must offer a Basic (government defined) policy to anyone who applies
- The Basic package is almost comprehensive
- Insurers are compensated for insuring higher-risk patients from the risk equalization fund

- Insurers can offer complementary health insurance packages under free market conditions
- Enrollees have the right to change their insurer at the end of every calendar year if not satisfied (insurers cannot refuse patients)

These elements are intended to ensure, among other things, that all Dutch citizens have the same basic (comprehensive) level of health insurance regardless of ability to pay. It also protects against insurance companies discriminating against patients based on their health condition and risk of needing care.

To breed efficiencies and improve value-for-money, competition is introduced into the system. Competition exists at two levels: between health insurance companies which vie for enrollees and also between healthcare providers (new and previously existing), which vie for contracts with health insurance companies. How these two levels of competition exists, is explored briefly.

Insurance companies can offer different coverage packages. Although, the cost of the basic (government defined) plan is predefined, additional, more elective coverage (e.g. additional dentistry, eye-wear, cosmetic surgery, alternative medicine and/or Viagra) and its costs can be set by competing insurance companies. Insurance companies can also compete in term of the level of service they provide (e.g. walk-in insurance consultations, online claims, and direct billing options) to entice enrollees to their company. In the same manner, citizens can shop around for the coverage and service level that best fits their needs.

The post-2006 era health system also creates competition among healthcare providers enticing them to provide better care for less money. Although being brought on gradually, the remuneration amounts per diagnosis related group (paid by insurers to providers), can be negotiated. This allows insurance companies to purchase services in bulk at a discount and provides less uncertainty for health providers in relation to demand. Furthermore, it provides incentives for hospitals to focus on core competencies and improve efficiencies through specialization. Similarly, new private entities are entering the market offering specific procedures which were traditionally only offered in hospital settings.

In time, insurers may select providers based on quality of care as well, but to-date this rare because “there is limited valid and reliable information about where to go for the best care” (Westert et al. 2009). Clearly, measuring quality of care in an objective way is an important metric needed in order to allow healthcare purchasing decisions to be based on more than just cost factors.

The crucial underpinning of this system is to use competitive markets and insurance companies to force a higher performing healthcare system. It is our experience that this pressure is being felt by healthcare providers and as a result there is a greater demand to use quantitative analysis to improve their operations.

For a comprehensive review of the Dutch healthcare system see Schäfer et al. 2010). For discussions on how applicable the Dutch healthcare system is in the American context, see Enthoven & van de Ven 2007) and Seddon 2008).

## **Specific projects in three big problem areas**

### **Identifying capacity needs**

As with the Intensive Care and Obstetrics units described by Linda Green, the operating theatre and inpatient wards face similar complexity and uncertainty. This includes multiple patient types, variable service times (and lengths of stay), and uncertain demand. This has led to a significant number of studies of this hospital area (Vanberkel et al. 2010c) although with reportedly limited evidence of implementation (Cardoen et al. 2010). Identifying the capacity needs of the ward as a function of the operating theatre schedule can lead to improved patient flow and better resource utilization.

One such study was completed at the Netherlands Cancer Institute (NCI) (Vanberkel et al. 2011) where content experts and staff put forth Master Surgical Schedule (MSS) proposals. Subsequently, an operations research model was used to predict ward capacity requirements of each proposal. Based on projected periods of over- and under-utilization, staff from the wards and the operating theatres reached a consensus on an appropriate schedule. After implementing the new MSS, a review of bed-use statistics showed it was achieving the desired result. The model and analysis gave the hospital the ability to quantify the concerns of multiple departments, thereby providing a platform from which a new MSS could be negotiated.

The model has since been implemented in the business intelligence system of NCI to facilitate future MSS negotiations. Furthermore, variants of this model have been applied in three other Dutch hospitals. At two of the hospitals the model was used to improve the workload balance on the inpatient wards. In the third hospital it was used to evaluate the allocation of beds to wards (Vanberkel 2011).

Another study looking at capacity needs was completed in oncology and used to determine the appropriate panel size for physicians (Vanberkel 2011). A physician's panel size is defined as the number of patients that s/he can effectively be accountable for. Typically this is studied in general practice settings where general practitioners want to know how 'big' their practice can be (i.e. how many patients they can be accountable for) before the waiting times for appointments becomes too long or overtime too frequent. By identifying the capacity needed for a given panel size, physicians can manage their clinics so as to guarantee certain performance levels.

Panel sizes in hospital environments have been studied less, although there are similar concerns. The characteristics of a hospital that distinguish it from a general practice include turnover rates of patients and multiple patient and appointment types. This is made more complex when treating chronic diseases, since these patients tend to require care and treatment for many years (WHO 2011). To determine a panel size in such an environment we model the panel size as the sum of patient-type specific random variables which we determine using queueing network models. We applied the panel sizing model in an oncology clinic that is part of the British Columbia Cancer Agency. We determined for a given patient mix the number of patients that can be seen in a stationary setting (i.e. by an established oncologist) and in a non-stationary setting (i.e. by a new oncologist). To the extent that the overall capacity of a region can be seen as the sum of its oncologists, the models aid in capacity planning decisions at the regional level as well.

A further factor to consider when identifying capacity needs is the reliability of the source providing the information. Consider an MRI scanning facility, with limited capacity, and several medical departments which compete for that capacity. The fairness of the capacity allocation by the radiology department depends on the quality of the information provided by the medical departments. When the departments over- or under-estimate the demand it can occur that the actual demand is less than the allocated capacity (i.e. the scanner sits idle) or the actual demand is larger than the allocated capacity. Both situations can arise simultaneously. In order to have a fair allocation, where all available capacity gets used, radiology should motivate medical departments to provide an honest forecast of their demand (Zonderland & Timmer 2011).

Using a generic Bayesian Game approach that stimulates the disclosure of true demand (truth-telling), capacity can be allocated in a fair manner and the conditions under which truth-telling is a Bayesian Nash Equilibrium (Zonderland & Timmer 2011).

### **Dedicated or flexible resources**

In limiting the range of services offered, specialized departments (or hospitals) use dedicated resources to reduce complexity and allow the department to concentrate on doing fewer things more efficiently. This in turn can lead to decreased service times. This philosophy has been the basis for modern manufacturing plants (i.e. focused factories) (Skinner 1985), where focus, simplicity and repetition aim to breed competence and is the strategy used at the much lauded Shouldice Hernia center (Heskett 1983). It has been argued that focused factories in healthcare can be a “solution to our current efficiency and productivity crisis” (Leung 2000).

In contrast to focused factories are the more common functional departments, which pool resources based on their function not on the type of demand. In pooled departments resources are flexible, instead of focused, and serve all demand, instead of specific (or specialized) demand. This setup benefits from economies of scale and follows from the adage that pooling resources is an easy way to gain efficiencies (Cattani & Schmidt 2005).

The decision of whether and to what extent to pool resources is complicated and depends on numerous clinic attributes such as appointment length, clinic load, number of resources, and patient demand. Furthermore, many of these attributes are interrelated, meaning that identifying one attribute’s influence in isolation from the others is extremely difficult. In general terms we have shown that clinic load, patient mix and variability are the most important factors. In particular, we know that pooling highly utilized resources from (specialized) clinics will result in little efficient gains due to economies of scale (Vanberkel et al. 2010a).

Although general guidelines and rules of thumb can help focus the pooling discussion on particular hospital areas, implementing a change of strategy (whether breaking a pooled clinic into multiple specialized clinics or vice versa) often requires a more detailed study reflecting actual clinic characteristics. Such a study is described below.

The NCI is considering the use of specialized clinics to treat patients with similar cancer diagnoses. From a patient satisfaction perspective this setup is preferred, and hospital managers want to know whether service time improvements in the unpooled setting are sufficient to compensate for any economy of scale losses caused by unpooling the functional departments. To support this decision making, a decision support tool was developed to compute the economy of scale losses which result from changing a pooled department into a focused factory style department. The decision support tool further calculated the service time improvements necessary to compensate for economy of scale losses. Managers can then discuss if such service time improvements are possible in the new specialized environment.

A specific application was in the chemotherapy department (Vanberkel et al. 2010b). Managers did not expect any decrease in service time would results from a specialized environment (mainly due to the fact that the majority of the time is spent waiting for the medicine to be absorbed by the body and hence there is little room for improved efficiency). Therefore, in the chemotherapy department the decision support tool computed the additional resources required to compensate for the economy of scale losses. Using the decision support tool in this manner can facilitate the decision regarding which departments to include in the focused factories.

### **Designing and managing patient-centered processes of care**

In designing patient-centered processes of care we aim to optimize a patient's entire clinical course. We take this broad scope in an effort to discourage situations where clinicians advance the patient-at-hand, unknowingly at the expense of other patients. For example, a physician may admit a patient to a bed in order to reduce access time for diagnostics (inpatients are typically given priority access to diagnostic services) and thereby advance their patient ahead of other patients. Of course, this "gaming" of the system leads to many undesirable effects, and results in patient-centeredness that is not equitably distributed. Achieving patient-centered processes of care for all patients often means considering and improving how multiple departments treating the same patients can do so in a seamless manner and also changing the mindset of physicians from patient to process centric.

Numerous literature reviews (Fletcher & Worthington 2009, Vanberkel et al. 2010c) have found that managers often consider hospital departments in isolation when designing processes and making decisions. This is often reflected in the models used by academics to support decision making, although this is changing (Vanberkel 2011). Typical examples include designing surgical schedules which consider the capacity of the surgical ward or understanding how emergency department congestion is caused by an inability to admit patients to an overcrowded medical ward.

It is not surprising that the flow of inpatients is often studied, since their costs are high and easily measured using patient length of stay data. Outpatient processes are studied less, presumably since these costs are often hidden (i.e. patients waiting at home and outside the hospital do not directly affect a hospital's bottom line, whereas the patient in the hospital does). There is also a trend to perform an increasing number of procedures in outpatient clinics (Cayirli & Veral 2003). As such, there should be renewed attention paid to the operations of outpatient clinics and, in particular, how these clinics

function together to provide seamless patient-centered care. Results from recent studies of outpatient clinic operations are presented below.

Prior to surgery, patients often visit a pre-anesthesia evaluation clinic where patients consult several medical professionals and the risks of, and requirements for, anesthesia are determined. This process was studied at Leiden University Medical Center in an effort to see if a reorganization of an outpatient clinic could decrease the time required to approve (or not approve) a patient for surgery (Zonderland et al. 2009).

Queuing theory is used to model the initial set-up of the clinic and possible alternative designs related principally to the use of walk-in appointments versus scheduled appointments, rescheduling appointments and the reallocation of tasks. The chosen intervention was implemented and resulted in shorter turnaround times for approving patients for surgery. Patient arrivals increased sharply over one year by more than 16%; however, patient length of stay at the clinic remained essentially unchanged. If the initial set-up of the clinic would have been maintained, the patient length of stay would have increased dramatically.

Another approach to patient-centered care is to use clinical pathways for similar patient types. Given the vast number of hospital facilities that a patient has to visit, hospitals aim to optimize the flow of patients following clinical pathways. This is often achieved by prioritizing them in the appointment planning process or by reserving specific resources for them. As a result, regular patients who are not following a clinical care pathway may experience a decrease in service.

Using a queuing model, in Zonderland et al. 2011) we develop an approach to measure the trade-off between accessibility for patients on the care pathway and the accessibility of regular patients. The methodology is used as the basis of a capacity planning tool, allowing managers to study the trade-off between the delay for walk-in patients and the probability the number of slots reserved for the care pathway patients is not sufficient.

Other approaches to become patient-centered and improve the seamless transition of patients involve focusing on departments which play a supportive role but which are utilized by almost all patients (e.g. diagnostic imaging and pharmacy). In Masselink et al. 2012) we investigate the impact of pharmacy policies on patient waiting time at the NCI. The study evaluated whether a reduction in waiting time resulting from medication orders being prepared in advance of patient appointments was justified, given that medications prepared in advance are wasted when patients arrive too sick for treatment.

Within this context, we derive analytic expressions to approximate patient waiting times and wastage costs, allowing management to see and understand the tradeoff between these two metrics for a variety of policies. This model was used by hospital management to select a new policy for prescribing which medicines to prepare in advance of patient appointments. It is expected that this policy will halve the waiting time, while only increasing the pharmacy's costs by 1-2%.

## Summing up

The examples above are but a few of the many projects ongoing in the Netherlands and in the world. Given the receptiveness of healthcare providers in the Netherlands to employ operations analysis, we have seen great strides in terms of implementing results and discovering scientifically novel research questions. Our formula to achieve the most from collaborations with healthcare providers has worked well in this context and we believe it to be a fitting framework for collaborations in other countries as well.

In conclusion, we summarize the three principles that have guided us to fruitful hospital partnerships. Firstly, our principle focus is on solving the healthcare provider's problem. Through careful project selection we ensure that meaningful scientific contributions result. Our focus is not on *applying* models; we consider this to be a byproduct of *solving* scientifically interesting problems of concern to healthcare providers. Secondly, we accept that building relationships takes time and often we need a "quick win" to showcase how we can contribute and to build good will. Quick win projects should require little time and have demonstrable positive impacts. Thirdly, we invest in long term relationships with hospitals and ask that they do the same by funding (or co-funding) our PhD and MSc students.

## References

- Cardoen, B., Demeulemeester, E. & Beliën, J. (2010), 'Operating room planning and scheduling: A literature review', *European Journal of Operational Research* **201**(3), 921 – 932.
- Cattani, K. & Schmidt, G. M. (2005), 'The pooling principle', *INFORMS Transactions on Education* **5**(2), 47–52.
- Cayirli, T. & Veral, E. (2003), 'Outpatient scheduling in health care: A review of literature', *Production and Operations Management* **12**(4), 519–549.
- Dekker, W. (1987), [*Willingness to change; report of the committee on healthcare reform*], The Hague: Distributiecentrum overheidspublicaties.
- Enthoven, A. & van de Ven, W. (2007), 'Going Dutch—Managed-Competition Health Insurance in the Netherlands', *New England Journal of Medicine* **357**.
- Fletcher, A. & Worthington, D. J. (2009), 'What is a 'generic' hospital model? A comparison of 'generic' and 'specific' hospital models of emergency patient flows', *Health Care Management Science* **12**(4), 374–391.
- Heskett, J. L. (1983), *Shouldice Hospital Limited.*, Harvard Business School Case 683-068.
- Hulshof, P., Boucherie, R. J., Essen, J., Hans, E. W., Hurink, J. L., Kortbeek, N., Litvak, N., Vanberkel, P. T., Veen, E., Veltman, B., Vliegen, I. & Zonderland, M. (2011), 'ORchestra: an online reference database of OR/MS literature in health care', *Health Care Management Science* **forthcoming**, 1–2.

- Katsaliaki, K. & Mustafee, N. (2011), 'Applications of simulation within the healthcare context', *The Journal of the Operational Research Society* **62**(8), 1431–1451.
- Lagergren, M. (1998), 'What is the role and contribution of models to management and research in the health services? A view from Europe', *European Journal of Operational Research* **105**(2), 257–266.
- Leung, G. M. (2000), 'Hospitals must become Focused Factories', *BMJ: British Medical Journal* **320**(7239), 942–943.
- Masselink, I. H., van der Mijden, T. L., Litvak, N. & Vanberkel, P. T. (2012), 'Preparation of chemotherapy drugs: Planning policy for reduced waiting times', *Omega* **40**(2), 181 – 187.
- Schäfer, W., Kroneman, M., W., B., van den Berg M., G., W., Devillé, W. & van Ginneken, E. (2010), 'The Netherlands: health system review.', *Health Systems in Transition* **12**(1), 1–228.
- Seddon, N. (2008), 'Is the future Dutch?', *The Lancet* **372**, 103–104.
- Skinner, W. (1985), *Manufacturing: The Formidable Competitive Weapon*, John Wiley & Sons Inc, New York.
- Vanberkel, P. T. (2011), Interacting hospital departments and uncertain patient flows: theoretical models and applications, PhD thesis, Enschede, the Netherlands. <http://doc.utwente.nl/77176/>
- Vanberkel, P. T., Boucherie, R. J., Hans, E. W., Hurink, J. L., Lent, W. A. M. & Harten, W. H. (2011), 'Accounting for inpatient wards when developing master surgical schedules', *Anesthesia & Analgesia* **112**, 1472–1479.
- Vanberkel, P. T., Boucherie, R. J., Hans, E. W., Hurink, J. L. & Litvak, N. (2010a), 'Efficiency evaluation for pooling resources in health care', *OR Spectrum* **forthcoming**, 1–20.
- Vanberkel, P. T., Boucherie, R. J., Hans, E. W., Hurink, J. L. & Litvak, N. (2010b), Reallocating resources to focused factories: A case study in chemotherapy, in J. T. Blake & M. W. Carter, eds, 'International Perspectives on Operations Research and Health Care: Proceedings of the 34th Meeting of the European Working Group on Operational Research Applied to Health Services', pp. 152–164.
- Vanberkel, P. T., Boucherie, R. J., Hans, E. W., Hurink, J. L. & Litvak, N. (2010c), 'A survey of health care models that encompass multiple departments.', *International Journal of Health Management and Information* **1**(1), 37–69.
- Westert, G. P., & Verkleij, H., eds (2006), *Dutch health care performance report*, Bilthoven: RIVM.
- Westert, G. P., Burgers, J. S. & Verkleij, H. (2009), 'The Netherlands: regulated competition behind the dykes?', *BMJ* **339**(3397), 839–842.
- WHO (2011), World health organization: Chronic diseases. URL: [http://www.who.int/topics/chronic\\_diseases/en/](http://www.who.int/topics/chronic_diseases/en/).

Zonderland, M. E., Boer, F., Boucherie, R. J., de Roode, A. & van Kleef, J. (2009), 'Redesign of a university hospital preanesthesia evaluation clinic using a queuing theory approach', *Anesthesia & Analgesia* **109**(5), 1612–1621.

Zonderland, M. E., Boucherie, R. J. & Al Hanbali, A. (2011), 'Appointments for care pathway patients', *University of Twente Memorandum* **1961**, 1–13.

Zonderland, M. E. & Timmer, J. B. (2011), 'Optimal allocation of MRI scan capacity among competing medical departments', *European Journal of Operational Research* **forthcoming**, 1–15.