SALUS
GLOBAL KNOWLEDGE EXCHANGE

Building better healthcare – technologies to facilitate evidence-based design processes

Fraser Greenroyd, Dr Rebecca Hayward and Dr Shrikant Sharma | 25 Aug 2016

Against a backdrop of mandated efficiency savings and a focus on making better use of existing hospital space, it is becoming imperative not only to capture data but also to capture the right data early in a healthcare build or rebuild project, in order to help ensure hospital designs are efficient, productive and cost-effective. This paper presents two tools for automatically capturing data using computer vision technologies, in support of healthcare design projects.

Healthcare estates in the NHS are facing increasing pressures to provide effective care while delivering substantial cost savings. Changing demographics are causing the health service to experience severe strain[1] while the UK government aims to make efficiency savings of £5bn a year by removing unwarranted variations between healthcare providers.[2]

Of this £5bn, it has been proposed that savings of £1bn a year can be made through better estates and facilities management. This includes, for example, more efficient use of existing facilities instead of funding the development of new spaces.

Improving the efficiency of various hospital departments, including emergency departments,[3,4] surgery theatres,[5,6] pharmacy departments[7–10] and nursing units,[11–13] has been the focus of much work in academia and industry. A key theme of all these case studies and research projects is the capture and use of existing data to make informed decisions, provide recommendations and implement design changes or operational practices that improve the performance of the relevant department in some way.

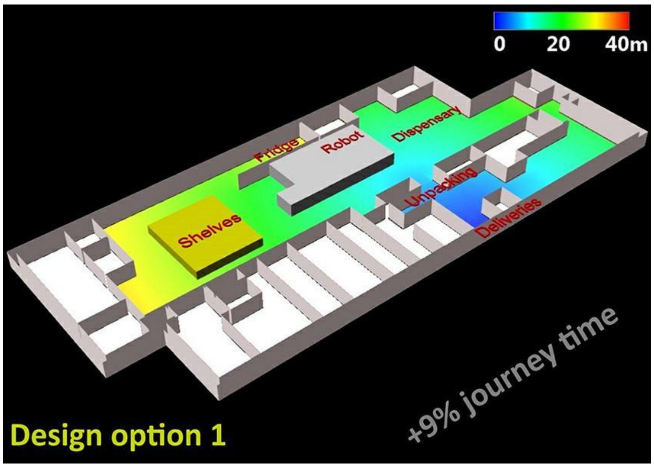

Figure 1a: Comparison of design options using anecdotal evidence (option 1) and data-based evidence (option 2)
Photo credit: Greenroyd, FL et al (2016). Ref: 7.

An early goal of any project should be to obtain reliable data on which to base and justify the project's recommendations and findings, or form the basis of design,[14] but this can be a long and arduous task. In healthcare environments, ethical concerns may prohibit certain data collection techniques, such as surveys and observations. In particular, there is the need to maintain patient confidentiality and privacy. It can also be difficult to obtain data from staff members; for example, through interviews, where this action may disrupt the level of patient care provided.

There are several well-established methods used for data collection, from questionnaires and work diaries[11–15] to the use of observations of current processes.[7,20] The use of work diaries and questionnaires allows for large amounts of data to be collected with minimal effort from researchers; this data, however, may be biased (intentionally or unintentionally), incomplete or oversimplified.[21,22]

Observations allow researchers to see first-hand the processes being undertaken in tasks, removing the possibility that the task description may be oversimplified. This approach, however, may require the use of trained observers to record data accurately, which can add to the cost of a project.[20] It may also be difficult to get the participants to agree to being observed,[23] and even if consent is given, participants may also behave differently under observation,[24–26] providing researchers with an inaccurate account of the processes and tasks.

Some of these challenges can be overcome by replacing

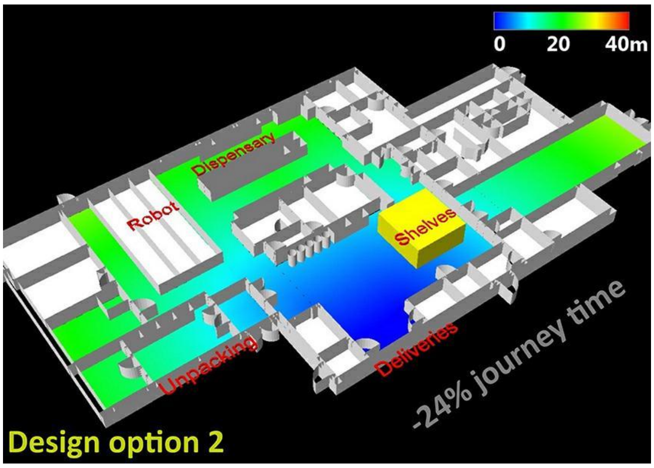

Figure 1b: Comparison of design options using anecdotal evidence (option 1) and data-based evidence (option 2)
Photo credit: Greenroyd, FL et al (2016). Ref: 7.

direct observation with the use of video recording and analysis. By capturing video, the need for a trained observer to be present is removed and may be easier to accommodate than an additional person. Surgical theatres, for example, may not be the appropriate setting for an additional non-medical person observing events, whereas video recording systems can be mounted discreetly to ceilings and walls for analysis at a later stage. The use of video analysis can also highlight interactions that may not be captured through traditional methods,[27,28] with video recordings made available for analysis multiple times, thus capturing more of the data available.

The use of video recording, however, often requires consent and may not always be beneficial or appropriate, particularly in places of patient care such as consulting rooms, where patient information may be discussed. In these instances, methods such as interviews and questionnaires may be more applicable, as they offer greater anonymity to participants.

RFID tagging has been used to great effect in tracking hospital staff,[12,29] patients [30] and equipment[31]. However, the equipment required to make use of RFID tagging can be expensive[30,31] and may prohibit its use in certain projects where budgets may be tight.

The use of data capturing methods, such as questionnaires and interviews, are appropriate for gathering qualitative data in healthcare, including perceptions of the quality of care, perceptions of waiting times, and perceptions of physicians. These methods have been used in numerous studies relating to quality of care.[16–18,32] However, for research into improving the efficiency or effectiveness of a healthcare facility, these methods are not particularly effective.

A recent example of this is demonstrated in a case study by Greenroyd et al,[7] where two designs of a pharmacy department were evaluated for operational productivity of pharmacy staff, following a data collection exercise that explored the working patterns in the existing facility.

The first design option was created following a series of workshops and interviews with pharmacy staff, and was compared with the existing building using the metric of walking distance and time spent walking over a working day. It was found that this design, produced from anecdotal evidence, predicted a 9% decrease in operational productivity. A second design option was produced following data extraction from video observations to identify common adjacencies between functions. Subsequent analysis of the second design option indicated a predicted 24% increase in operational productivity.

The study gives an insight into the benefits of using quantitative data to form a basis for design over anecdotal evidence of existing processes and inefficiencies. Gathering this evidence, however, can take a significant length of time, with video analysis taking many days to complete manually.

Time costs associated with data collection may be a contributing factor to the continued use of anecdotal evidence over data-based evidence-in-design projects. As technology costs have decreased, the application of video analysis or RFID tagging is becoming a more feasible method of gathering data on hospital use. This paper introduces two new technology-based tools for gathering reliable quantitative evidence to inform design projects and operational decisions for new and existing healthcare facilities.

Tool 1: SmartCounter3D

SmartCounter3D is a high-level occupancy-capturing device that measures current occupancy, as well as flow rates entering and exiting a space. This tool uses the Microsoft Kinect camera for desktop use to capture people movement across an entrance space. It uses toolkits for 3D people detection available in the Kinect software development kit (SDK), combined with image-processing techniques to filter noise and prevent inanimate objects being transported and classed as additional people entering the space. As people enter the camera's field of vision, they are detected and tracked until they leave.

A crossing completed by one person (a crossing being defined as a person entering the field of vision from one side and exiting it from the other) increments a counter that tracks the number of people who have moved in a given direction (either to the left or right). These counts provide information on how many people have entered a space and how many have exited. The difference between these two counts provides the current occupancy of the space at that moment. In addition, the route of the crossing is also captured, highlighting interactions and conflicts between in-flows and out-flows. Figure 2 illustrates how this works.

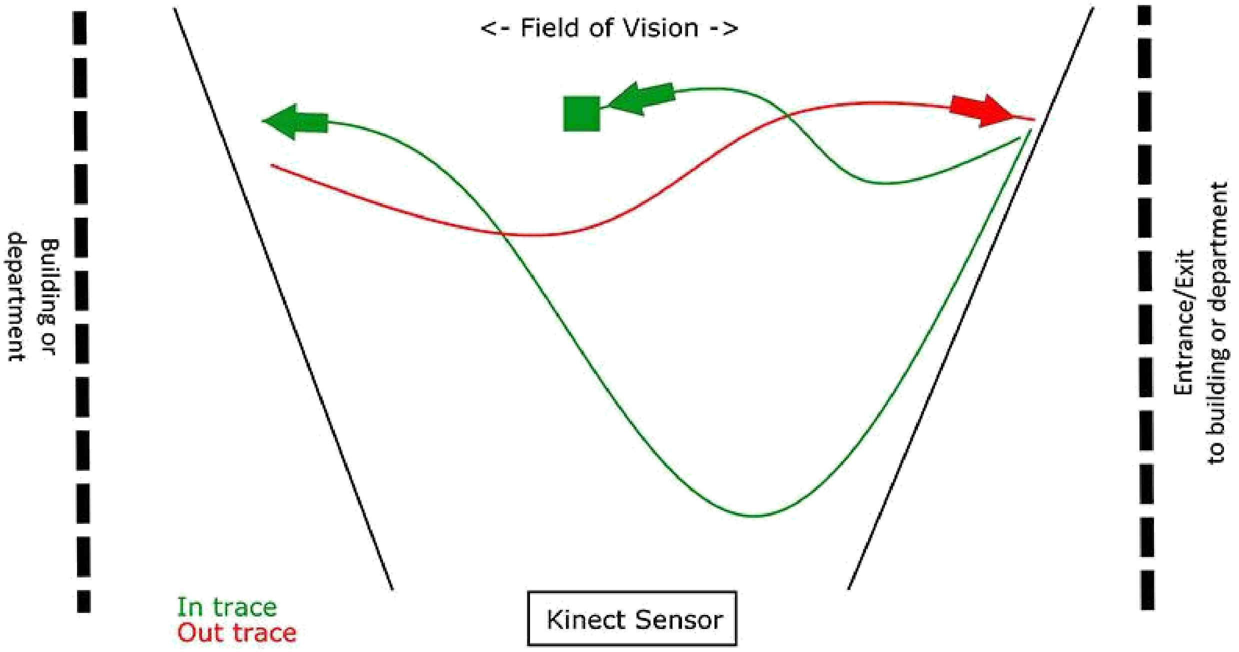

Figure 2: Diagrammatic illustration of SmartCounter3D

SmartCounter3D can be set up above the entrance or access point to a space, out of the way of pedestrian traffic, to monitor movement. This allows data to be collected unobtrusively and, once installed, the camera can be left to capture long-term flow trends and occupancy changes. The data that this tool provides allows an analysis of occupancy over time, as well as the peak flow rates of people entering and exiting the space. Figure 3 shows an example graph produced using flow data from the SmartCounter3D tool.

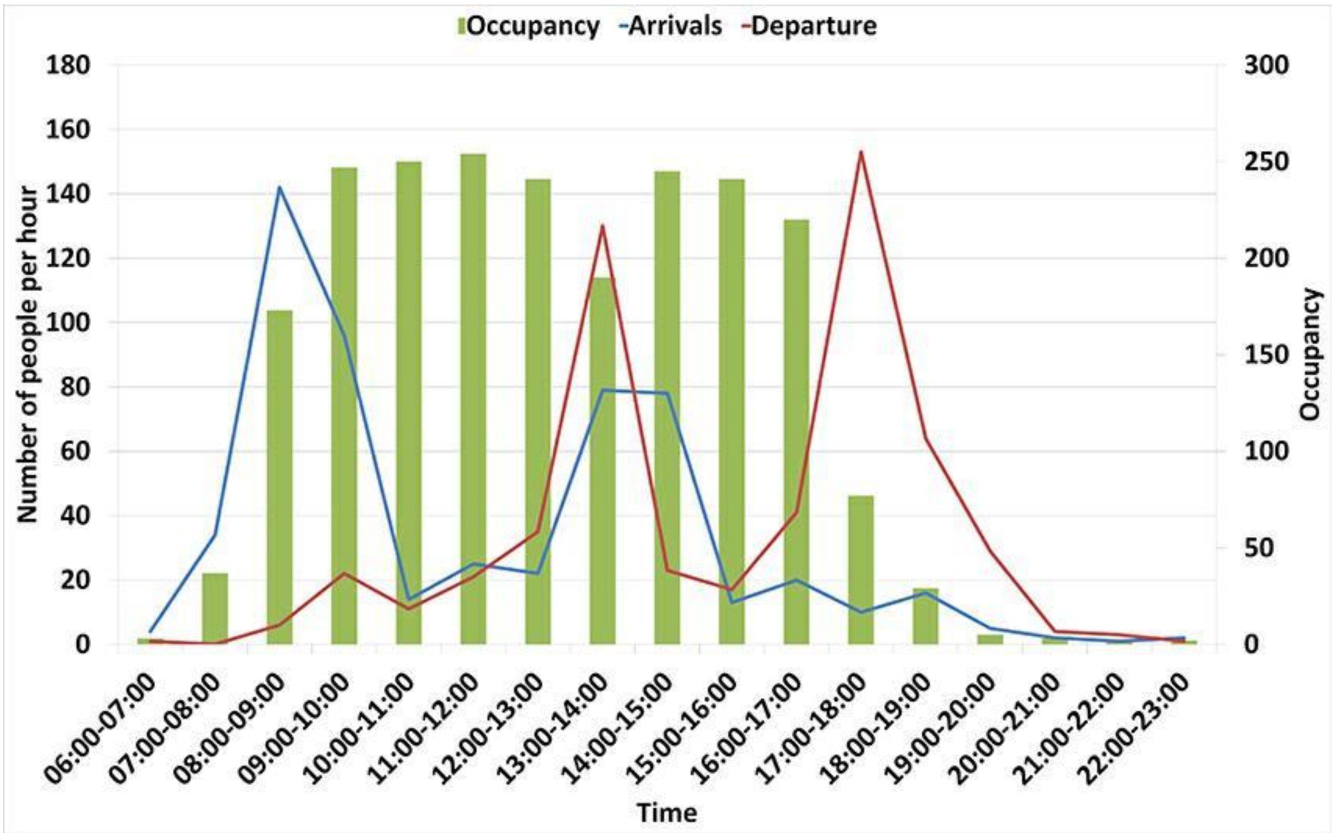

Figure 3: Example flow output for SmartCounter3D

The application of SmartCounter3D can be varied and provide information on how often a space is used and at what times. Long-term analysis can be used to inform when the peak periods occur or when the best time to close a space for maintenance might be, or what the impact of such an action might be. In areas with multiple entrances or exits, multiple Kinect cameras can be set up to work in parallel to capture the data of each entrance. This can provide additional information, such as which entrances experience greater flows, bringing insight on the impact of closing certain access points.

The data collected, however, is limited solely to occupancy and flow rates. The tool is currently unable to provide dwell-time data when the occupancy exceeds one, utilisation data for specific activities, or identify individuals. It could, however, be extended to incorporate additional computer vision algorithms that would allow for the detection of staff members and provide separate analysis on their flows compared with patient flows.

Tool 2: SmartCounter

SmartCounter is an automated video analytics tool for capturing occupancy levels, activity utilisation and dwell times. It uses technologies found in the OpenCV libraries that allow for the processing and analysis of video footage. Unlike SmartCounter3D, which analyses the total movements in and out of a space, SmartCounter is capable of analysing several specific areas within its field of view defined by the user. This allows it to provide occupancy data for specific activities; for example, within waiting areas, where the occupancy of each individual seat can be recorded.

SmartCounter can analyse video footage from a variety of options, including CCTV feeds, camera phones, or home video camcorders. Video footage is analysed using regions of interest that are created by the researcher during the analysis phase, ensuring analysis is focused only on the target areas. This removes some of the restrictions on camera placement for capturing data, allowing the researcher to choose the optimum camera location for their given task; for example, at a safe location away from circulation routes. Figure 4 shows regions of interest being drawn in a hospital waiting area. Alternatively, a region may be drawn around a self-service check-in point, and SmartCounter would be able to inform how much that check-in point is used over a given period.

Figure 4(a): Regions of interest for a waiting area with occupancy graph

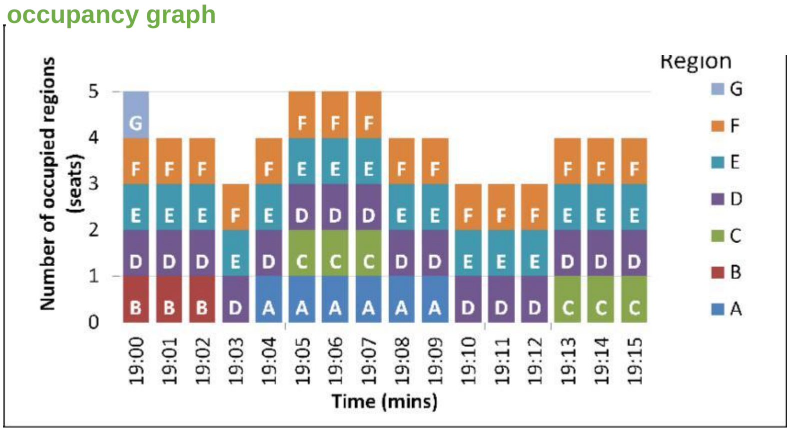

Figure 4(b): Regions of interest for a waiting area with occupancy graph

These tools allow researchers, designers and consultants to capture movement data, occupancies, dwell times and utilisation figures for a range of scenarios. The resulting data enable a clear, detailed analysis and understanding of the current situation in a facility. Rather than being reliant on anecdotal descriptions of how full might be a waiting area, the use of these tools provides evidence on actual waiting room occupancy with minimal effort.

Both tools can be installed and operated with minimal interference to the operations of the healthcare facility under investigation, and provide meaningful data without requiring researchers to be present. Where cameras are used to record situations, the analysis of footage can take significant time when undertaken manually. These tools, however, perform that analysis automatically, saving research time that can be better spent on working with the data to optimise the design. Table 1 compares the results of analysing waiting-room footage to obtain occupancy levels using SmartCounter against a manual analysis.

The level of detail in the data provided by both tools also exceeds that available from reasonable manual observations, which may be conducted using activity sampling – a method of capturing data without the overheads of continuous observation. Developed in 1927 by LHC Tippet,[33] activity sampling allows researchers to capture a subset of observations (the samples) and apply statistical calculations to infer the total activity usage. The greater the number of samples the researcher is able to record, the greater confidence a researcher should have in the data captured.[34]

Table 1: Speed test results comparing SmartCounter to manual analysis

Video length	Regions of interest	Time to analyse (manual)	Time to analyse (automated)	Samples collected (manual)	Samples collected (automated)
50 min	1	35 minutes	27 seconds	50	3000

60 min	18	20 minutes	2 min 1 sec	12	3600

Unlike activity sampling, SmartCounter3D and SmartCounter both provide continuous analysis. SmartCounter3D records the people flows for as long as the equipment is installed at a resolution of 30 frames per second, providing analysis at an approximate rate of one sample every 0.03 seconds. SmartCounter has the capability of providing analysis for every frame in a recorded video, with the frame rate dependent on the video quality used. This provides an in-depth understanding of the current situation at the facility undergoing research, allowing for more informed judgements to be made.

Discussion

The use of data in the design and operation of healthcare facilities plays an important role in ensuring hospitals continue to provide effective and efficient care while meeting cost-saving measures. Gathering this data can be costly, however, both in terms of the time it takes and the equipment required. SmartCounter3D and SmartCounter have been developed to cover a wide range of data-capturing aspects in a cost-effective manner. SmartCounter3D, whose biggest cost is that of a Microsoft Kinect camera, can be set up out of the way with ease and left to monitor continuous people flows and occupancy levels of spaces, without the need for someone to monitor the space manually. Similarly, SmartCounter can be used to analyse video footage from a variety of sources, so set-up costs are limited to that of video camcorders, if other footage, such as CCTV, is unavailable.

The use of computing power to analyse the existing situation of a healthcare facility allows for a greater number of data points to be collected through the use of continuous observations, as opposed to those produced manually. This does not mean, however, that the use of automated data-capture techniques is completely without drawbacks. The majority of the time savings associated with these tools are the result of the speed with which the tools conduct the analysis on footage captured – but the footage itself still takes time to record and retrieve. If, for example, there is a desire to understand how waiting room occupancy fluctuates over a week, there will still be a need to record a week’s worth of footage to analyse. Similarly, SmartCounter3D captures the flows in real time, so it would take a week to accumulate such data.

The time required to capture enough data to provide effective design or operational recommendations should be carefully considered when embarking on a project. Depending on the nature of the project, the time required to capture data for analysis does not necessarily require a halt in the research; rather, the use of the tools presented in this paper grant researchers the freedom to explore other avenues where automated technologies may not be appropriate. A study into waiting-area occupancy over the course of a week, for example, can be accurately captured using either SmartCounter3D or SmartCounter. How patients perceive the waiting area (such as welcoming, or uninviting) may, however, be captured best using qualitative methods.

The use of these tools can be varied owing to the generic implementation of the algorithms behind them, and can be used to capture a multitude of data, including occupancy, dwell and waiting times, utilisation, and flows. The data captured can be used to answer a variety of questions that help inform the design and operation of a facility, such as how long patients are waiting, how many seats does a waiting area need, what is the visitor to patient ratio, how early do patients arrive, or when are the peak operating times. Some of these questions may need multiple data sources to answer effectively, but such data can be used to inform a mix of projects – from department (re)design or testing whether departments can be merged, to operational studies looking at the impact of closing access points, to activity and equipment utilisation. The data can also be used to inform future demand or studies that look at the impact of increasing patient throughput, in order to future-proof healthcare designs.

Limitations

Although the use of camera recording equipment is commonplace in the world today, it should not be ruled out that if people know they are being watched, they may behave differently to when they are not. This may be countered by ensuring the placement of video cameras is as unobtrusive as possible, to allow people to continue their day-to-day activities unhindered.

For SmartCounter3D, there is a need for the camera to have an unobstructed view of the entrance area being analysed. This can be overcome, however, with a high camera placement looking down on the scene. Similarly, SmartCounter may be distorted if there is too much noise around the regions of interest drawn by the user, or if the regions of interest are drawn incorrectly by the user; for example, around two seats, as each region only counts one person. Similarly, using SmartCounter to analyse the utilisation of activities will provide an accurate level of utilisation over time, but it would not be able to inform necessarily how many people were using the activity at any one time.

Conclusion

This paper has presented two tools for automatically capturing data using computer vision technologies, in order to support healthcare design projects. The use of data in such projects is vital to ensure a thorough understanding of the current situation for which improvement is sought.

This has been demonstrated through the earlier example of a pharmacy department, where design based on anecdotal evidence showed a potential drop in productivity, compared with an evidence-based design making use of captured quantitative data. The tools presented here can be used in a wide variety of applications, from waiting area occupancy to activity utilisation, to understanding the flow patterns in and out of a space. The data these tools capture can greatly facilitate evidence-based

design practices to aid healthcare design projects. Additionally, the data collected can be used to evaluate and compare operational practices, supporting better use of existing estates where redesign is not possible. Capturing the right data early in the project – for example, by using tools such as SmartCounter3D and SmartCounter – can help ensure hospital designs are efficient, productive and cost-effective.

Authors

Fraser Greenroyd is a research engineer at Loughborough University who is also working closely with the Smart Space team at BuroHappold Engineering. Dr Rebecca Hayward is a senior people-flow consultant at BuroHappold Engineering, working in the Smart Space team. Dr Shrikant Sharma is group director at BuroHappold Engineering.

References

1. Department of Health. The NHS Constitution. London; 2013.
2. Coles, LC. Operational productivity and performance in English NHS acute hospitals: unwarranted variations. London; 2016.
3. Gunal, M and Pidd, M. Understanding accident and emergency department performance using simulation. Simulation Conference, 2006. WSC 06. Proceedings of the Winter. 2006; 446–452.
4. Bernstein, S et al. The effect of emergency department crowding on clinically oriented outcomes. Academic Emergency Medicine. 2009; 16(1):1–10.
5. Marcario, A. Are your hospital operating rooms ‘efficient’? Anesthesiology. 2006; (2):233–243.
6. Dexter, F and Epstein, R. Typical savings from each minute reduction in tardy first-case-of-the-day starts. Anesthesia & Analgesia. 2009; 108(4):1262–7.
7. Greenroyd, FL et al. Using evidence-based design to improve pharmacy department efficiency. HERD: Health Environments Research & Design Journal. 2016; 1–14.
8. Reynolds, M et al. Using discrete event simulation to design a more efficient hospital pharmacy for outpatients. Health Care Management Science. 2011; 14:223–236.
9. Mukherjee, AK. A simulation model for management of operations in the pharmacy of a hospital. Simulation. 1991; 56:91–103.
10. Maviglia, SM et al. Cost-benefit analysis of a hospital pharmacy bar-code solution. Archives of internal medicine. 2007; 167:788–794.
11. Burgio, L et al. A descriptive analysis of nursing staff behaviors in a teaching nursing home: Differences among NAs, LPNs, and RNs. The Gerontologist. 1990; 30(1):107–112.
12. Hendrich, A et al. A 36-hospital time and motion study: how do medical-surgical nurses spend their time? The Permanente Journal. 2008; 12(3):25–34.
13. Furåker, C. Nurses’ everyday activities in hospital care. Journal of Nursing Management. 2009; 17(3):269–277.
14. Lethbridge, T, Sim, S and Singer, J. Studying software engineers: data-collection techniques for software field studies. Empirical Software Engineering. 2005; 311–341.
15. Sun, B, Adams, J and Orav, E. Determinants of patient satisfaction and willingness to return with emergency care. Annals of Emergency Medicine. 2000; 35(5):426–434.
16. Chang, J et al. Patients’ global ratings of their health care are not associated with the technical quality of their care. Annals of Internal Medicine. 2006; 665–672.
17. Ridic, G, Gleason, S and Ridic, O. Comparisons of health care systems in the United States, Germany and Canada. Materia Socio-medica. 2012; 24 (February):112–120.
18. Anderson, R, Barbara, A and Feldman, S. What patients want: a content analysis of key qualities that influence patient satisfaction. J Med Pract Manage. 2007; 255–261.
19. Olson, D and Windish, D. Communication discrepancies between physicians and hospitalized patients. Archives of Internal Medicine. 2010; 170(15):1302–1307.
20. Mackenzie, CF and Xiao, Y. Video techniques and data compared with observation in emergency trauma care. Quality and Safety in Health Care. 2003; 12 Suppl 2:ii51–i57.
21. Paetsch, F, Eberlein, A and Maurer, F. Requirements engineering and agile software development. 2012 IEEE 21st International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises. 2003; 308–313.
22. Maiden, NaM and Rugg, G. ACRE: selecting methods for requirements acquisition. Software Engineering Journal. 1996; 11(3):183.
23. Weinger, MB et al. Video capture of clinical care to enhance patient safety. Quality & Safety in Health Care. 2004; 13:136–144.
24. Bateson, M, Nettle, D and Roberts, G. Cues of being watched enhance cooperation in a real-world setting. Biology letters. 2006; 2 (June):412–414.
25. Burnham, TC and Hare, B. Engineering human cooperation. Human Nature. 2007; 18:88–108.

26. Ernest-Jones, M, Nettle, D and Bateson, M. Effects of eye images on everyday cooperative behavior: a field experiment. Evolution and Human Behavior. 2011; 32(3):172–178.
27. Iedema, R et al. Video research in health. Qualitative Research Journal. 2007; 6:15–30.
28. Luff, P, Hindmarsh, J and Heath, C. Workplace Studies: Recovering Work Practice and Informing System Design. Cambridge University Press; 2000.
29. Greenwood, D, Sharma, S and Johansson, A. Mobility modelling in a process-constrained environment: modelling the movements of nurses in a neonatal intensive care unit. In: Traffic and Granular Flow ’13. 2015; 233–241.
30. Hosaka, R. Feasibility study of convenient automatic identification system of medical articles using LF-band RFID in hospital. Systems and Computers in Japan. 2004; 35(10):74–82.
31. Wicks, AM, Visich, JK and Li, S. Radio-frequency identification applications in hospital environments. Hospital Topics. 2006; 84(3):3–8.
32. Camacho, F et al. The relationship between patient’s perceived waiting time and office-based practice satisfaction. NC Med J. 2006; 67(6):409–413.
33. Kelly, J. The study of executive behaviour by activity sampling. Human Relations; 1964.
34. Robinson, MA. Work sampling: methodological advances and new applications. Human Factors and Ergonomics in Manufacturing & Service Industries. 2010; 20(1):42–60.