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Annotated Bibliography on Lean in Healthcare Organizations

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Overview

This annotated bibliography update compiles summaries and findings of systematic reviews and primary research articles focused on lean management's application in healthcare settings, with the majority of summarized articles published within the last 3 years. All papers were published between 2000 and 2017. Primary research articles were restricted to those that focused on lean or lean-Six Sigma in healthcare. Articles are organized by whether they addressed 1) health, process, satisfaction, and cost outcomes; 2) components, methods, barriers, and facilitators of lean healthcare interventions; or 3) lean tool development, testing, and validation in healthcare. For primary articles, papers are further sub-categorized by the organizational unit (e.g. ER, surgery, laboratory) in which lean was implemented.

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Systematic Reviews

Systematic reviews assessing health, process, satisfaction, and cost outcomes of Lean in healthcare organizations

Acute Care

Deblois, S. & Lepanto, L. (2015). 'Lean and Six Sigma in acute care: a systematic review of reviews' *International Journal of Health Care Quality Assurance*, 29 (2), pp. 192-208.

This paper was a systematic review of literature reviews summarizing lean and Six Sigma management techniques and outcomes in acute care settings. The authors searched 8 databases and assessed methodological quality of included reviews using AMSTAR. A narrative synthesis was then performed, and data reported according to PRISMA standards. There were 149 articles published between 1999 and January 2015 that were identified and reviewed, with 7 publications ultimately being included in the systematic review. Quality of evidence ranged from poor to fair.

The most consistent finding was that lean and Six Sigma seem to be better suited for processes involving a linear sequence of events. The review also found that tracked outcomes were most often related to processes and quality, and acute settings most often described were operating suites, ICUs, and EDs. Lean and Six Sigma were found to be valuable process optimization approaches in the acute care setting. The authors stated that more studies of high methodological quality were needed to better understand components and barriers to lean and Six Sigma implementation. Field studies comparing the effects of lean and Six Sigma to other quality improvement initiatives were suggested as an area of future research.

Emergency Department

Holden, R.J. (2011). 'Lean Thinking in Emergency Departments: A Critical Review', *Annals of Emergency Medicine*, 57 (3), pp. 265-278.

This article critically reviewed 18 articles describing the implementation of Lean in 15 Emergency Departments (EDs) in the United States, Australia, and Canada. The author used an analytical framework from occupational research to generate 6 core questions regarding Lean's effect on ED work structures and processes, patient care, and employees, as well as Lean's success factors. Identified Lean process changes often involved the creation of separate patient streams along with structural changes including new technologies, communication systems, staffing modifications, and reorganization of physical space. Patient care was usually found to improve, as many EDs reported decreases in length of stay, waiting times, and proportion of patients leaving the ED without being seen. Few null or negative effects were reported, with explored patient effects typically limited to patient satisfaction. The effect on employees was rarely measured, but there were some indicators of positive effects. Factors for Lean success included employee involvement, management support, and preparedness for change. The author concluded that Lean appears to offer significant improvement opportunities in spite of methodological concerns, and that more research is needed on Lean's effects on patient health and employees and how Lean can be best implemented in healthcare.

Geriatrics

Butler, M. (2016). *Introduction of the Productive Ward: Releasing Time to Care to Programme. Introducing the Programme to a Care of the Older Person Unit*. [MSc Thesis]. Dublin: Royal College of Surgeons in Ireland.

This broad literature review sought out key themes in papers on the introduction of the Productive Ward Programme, which began in the UK National Health System and was based on lean principles. The author states that the Productive Ward Programme was developed with the aim of empowering staff to identify areas for improvement by providing information, time, and skills to teams while allowing them to take ownership of the quality of care in their ward. Databases searched included Cinahl, Pubmed, Emerald, and Google Scholar. Results were limited to articles published in English between 2006 and 2016. Key terms used were 'productive ward,' 'productive community hospital,' and 'releasing time to care.' The search was then refined to review articles examining the benefits of introduction, implementation, and adoption of the program within the healthcare setting.

Key themes found were the importance of communication with stakeholders, need for positive leadership at multiple levels, alignment of the initiative with organizational goals, and support from

senior leadership. The literature also noted that the Productive Ward emphasized different key points of the program depending on the audience, and that the program could bridge gaps between executive leadership and frontline staff through a shared language helping to foster shared interests and values. Open communication was repeatedly stated as a vital part of successful implementation.

General

Glasgow, J.M., Scott-Caziewell, J.R.; Kaboli, P.J. (2010). 'Guiding Inpatient Quality Improvement: A Systematic Review of Lean and Six Sigma', *The Joint Commission Journal on Quality and Patient Safety*, 36 (12), pp. 533-540.

A systematic literature review was conducted to determine whether Lean, Six Sigma, or Lean Sigma have been effectively used to create and sustain improvements in the acute care setting. Databases were searched for articles published in the healthcare, business, and engineering literatures. Study inclusion criteria required identification of a Six Sigma, Lean, or Lean Sigma project; quality improvement efforts focused on hospitalized patients; descriptions of project improvements; and reported results. 47 out of 539 potential articles met inclusion criteria. The authors concluded that Lean, Six Sigma, and Lean Sigma all can address a wide variety of acute care problems, but that the true impact of these methodologies is difficult to judge given the lack of rigorous evaluation or evidence of clearly sustained improvements. More research is needed to provide greater understanding of these approaches and how to achieve sustainable improvement.

Moraros, J., Lemstra, M., and Nwankwo, C. (2016). 'Lean interventions in healthcare: do they actually work? A systematic literature review', *International Journal for Quality in Health Care*, 28 (2), pp. 150-165.

A systematic literature review was conducted to assess the effect of Lean on worker and patient satisfaction, health and process outcomes, and financial costs. 9 different databases (including PubMed and Medline) were searched for peer-reviewed articles that examined a Lean intervention and included quantitative data, resulting in 22 articles inspected. Data on design, methods, interventions and key outcomes were extracted and collated. They found that there was 1) no statistically significant association with patient satisfaction and health outcomes, 2) a negative association with financial costs and worker satisfaction, and 3) a potential but inconsistent benefit to process outcomes like patient

flow and safety. The authors concluded that evidence to date does not support the belief that Lean leads to healthcare quality improvements. They called for more rigorous, higher quality and better conducted scientific research to definitively ascertain the impact and effectiveness of Lean in healthcare.

Shazali, N.A., Habidin, N.F., Ali, N. et al. (2013). 'Lean Healthcare Practice and Healthcare Performance in Malaysian Healthcare Industry', *International Journal of Scientific and Research Publication*, 3 (1), pp. 301-305.

The authors conducted a literature review of Lean healthcare practices. They aimed to analyze the relationship between Lean healthcare and healthcare performance as defined by 3 elements: financial performance, customer satisfaction, and employee performance. The researchers found that while previous studies have identified critical success factors for Lean implementation, limited empirical studies have investigated the relationship between Lean and healthcare performance. They also proposed future research in designing a structured questionnaire to obtain pilot study data for healthcare practices in Malaysia.

Vest, J.R. and Gamm, L.D. (2009). 'A critical review of the research literature on Six Sigma, Lean and StuderGroup's Hardwiring Excellence in the United States: the need to demonstrate and communicate the effectiveness of transformation strategies in healthcare', *Implementation Science*, 4(1), pp. 35-43.

Vest and Gamm conducted a systematic literature review of 3 current popular change strategies, including Lean, and examined peer-reviewed evidence of their effectiveness. The authors found that studies universally concluded the strategies' success and applicability to a wide variety of settings and problems. However, the vast majority of these studies contained methodological limitations including weak study designs, inappropriate analyses, and failure to rule out alternate hypotheses. Additionally, many studies did not provide substantial evidence for lasting effects or changes in organizational culture. The paper concluded that improved design and analysis of these change theories would provide more effective guidance to healthcare managers; more rigorous evaluation of project consultants and partnerships with academic healthcare researchers were suggested as ways to accomplish this.

Systematic reviews identifying components, methods, barriers and facilitators for implementing Lean in healthcare organizations

General

Al-Balushi, S., Sohal, A.S., Singh, P.J., et al. (2014). 'Readiness factors for lean implementation in healthcare settings – a literature review', *Journal of Health Organization and Management*, 28 (2), pp.135-153.

This paper sought to determine readiness factors critical to the success of Lean applications in healthcare. To this end, a comprehensive literature review focusing on lean and lean healthcare was conducted. Commonly cited readiness factors were leadership, organizational culture, communication, training, measurement, and reward systems. The authors also found that an organization's ability to implement a decentralized management style and undertake an end-to-end process view were important, which was noted as particularly difficult for complex healthcare settings.

Andersen, H., Rovik, K.A., and Ingebrigsten, T. (2014). 'Lean thinking in hospitals: is there a cure for the absence of evidence? A systematic review of reviews', *BMJ Open*, 4, e003873.

The authors noted that there is conflicting evidence regarding Lean outcomes, with quantitative and qualitative studies often contradicting each other. The article aimed to identify factors facilitating intended outcomes from lean interventions, and to understand when and how different facilitators contribute. A 2-dimensional conceptual framework combining Shortell's *Dimensions of capability* and Walshes' *Domains of an intervention* was used in conducting a systematic review of lean review articles concerning hospitals, published in the period 2000–2012. Identified lean facilitators were then categorized according to the intervention domains and dimensions of capability provided by the framework. 23 factors were identified for successful Lean intervention, with supportive management and culture, training, accurate data, physicians and team involvement cited most frequently.

Brandao de Souza, L. (2009). 'Trends and approaches in Lean healthcare', *Leadership in Health Services*, 22 (2), pp. 121-139.

In this paper, Brandao de Souza conducted a systematic search and critical literature review of Lean healthcare articles up to 2008 in ten countries. The author employed search and metasearch engines to identify relevant works, using key words such as “Lean healthcare”, “Lean hospital”, and “Lean medical”. This search garnered over 90 sources, which the author then cross-referenced to find further works. Multiple speculative U.S. studies reported positive results from use of Lean initiatives in improving patient flow and in both clinical and non-clinical settings. However, none of these studies provided explicit evidence of their results. The review also found that healthcare lags far behind the manufacturing industry’s level of excellence in Lean applications, and that many case studies have been branded as Lean while only applying one or two of Lean’s concepts. Overall, this paper concluded that while there seems to be consensus over Lean’s potential for improving healthcare delivery, more critical and concrete evidence is needed. Cross-organizational interaction was stated as a further avenue of exploration.

Curatolo N., Lamouri S., Huet J., & Rieutord A. (2014). ‘A critical analysis of Lean approach structuring in hospitals,’ *Business Process Management Journal*, 20 (3), pp. 433-454.

This literature review analyzed published lean literature in the hospital setting. A methodological maturity-level framework was used as well as 11 activities defined by the authors as characteristic of business process improvement (BPI). The maturity-level framework defined levels from 0-6 to indicate how much methodological support an article had to allow other practitioners to replicate its results. Researchers defined 0 as “Lean approach not described or poorly described” and 6 as “Lean approach structured with a procedure model, techniques, results, role defined for each activity, and information model.” A total of 142 articles reporting lean process improvement in hospitals were selected, all of which sought to transform an existing process into an improved future process.

Most articles identified did not provide any description of the lean approach (level 0), preventing other practitioners from reproducing results. The authors focused the rest of their analysis only on articles with at least a procedure model described (\geq level 2). Only 17 out of 142 articles were found to be at least a level 2, and none were level 5 or 6. All 17 were case studies: ten were categorized as ‘manufacturing like,’ six as ‘patient flow,’ and one as ‘organizational’.

Each of the 11 BPI activities were quoted in at least half of the 17 articles. These activities were 1) understand the environment of the organization, 2) select a process to improve, 3) establish top management support, 4) organize a project team, 5) understand the selected process, 6) measure process performance, 7) analyze the process, 8) improve the process, 9) manage change through communication and training, 10) implement the new process, and 11) monitor performance indicators.

The authors recommend that hospitals introduce a lean approach starting at the micro-level by acting on one or more operational processes using a 'system-driven' approach. They also suggested use of the 11 BPI activities as a procedure model for lean approaches.

D'Andreamatteo, A. Ianni, L., Lega, F. and Sargiacomo, M. (2015). 'Lean in healthcare: a comprehensive review', *Health Policy*, 119(9), pp. 1197-1209.

A comprehensive literature review was conducted to find Lean healthcare articles published up to 2013. Thematic analysis was then performed to extract and synthesize data for 243 articles. Lean was mostly explored in a hospital setting, with theoretical works focusing mostly on barriers, challenges, and success factors. Underexplored areas of analysis included Lean sustainability, measurement frameworks, and system-wide approaches. Authors concluded that while promising, more conclusive findings on Lean are needed; particular investigation on the magnitude of investments required and engagement of the whole organization were suggested. Managers and policy makers were additionally encouraged to use research to learn how to play a pivotal role for more effective Lean implementation in different health contexts.

Mazzocato, P., Savage, C., Brommels, M. et al. (2010). 'Lean thinking in healthcare: a realist review of the literature', *Quality and Safety in Health Care*, 19(5), pp. 376-382.

The authors conducted a realist literature review to examine how Lean has been put into practice in healthcare and how it has worked. They limited their review pool to Lean healthcare applications that impacted patient care, and excluded hybrid approaches, resulting in 33 articles for review. A thematic analysis was then conducted. The authors noted 4 different change mechanisms: 1) understanding processes to generate shared understanding, 2) organizing and designing for effectiveness and efficiency, 3) improving error detection to increase awareness and process reliability, and 4)

collaborating to systematically solve problems to enhance continual improvement. They concluded that Lean has been successfully applied in a wide range of healthcare settings, and that most Lean healthcare implementations have reported narrower rather than system-wide applications, contrasting with Lean's holistic view. Recommendations for better implementation were to directly involve senior management, work across functional divides, pursue value creation for patients and other customers, and nurture a long-term view of continual improvement.

Plytuk, C.F., Gouvea da Costa, S.E., and Pinheiro de Lima, E. (2013). *Lean in Healthcare: A Systematic Literature Review and Social Network Analysis* [Masters thesis]. Curitiba, Brazil: Pontifícia Universidade Católica do Paraná.

The authors conducted a systematic review of 139 papers from the Lean Healthcare literature to identify groupings in the Lean research field. Bibliometric citation/ co-citation and Social Network analysis were used to investigate the articles sampled. Common paper themes involved Lean in context of the NHS UK, pathology laboratories, reduction of variability and Six Sigma, other laboratories, and emergency departments. Analysis of number of authors per paper found a high level of collaboration in Lean healthcare research, with 65% of papers having between 3-12 authors. The literature review concluded that the results revealed a still emergent field marked by poorly explored relationships and knowledge, indicating many possibilities for future research.

Poksinska, B. (2010). 'The Current State of Lean Implementation in Health Care: Literature Review', *Quality Management in Health Care*, 19 (4), pp. 319-329.

This article sought to discuss the current state of Lean healthcare implementation through a comprehensive literature review. It found that Lean healthcare improvement focused on 3 main areas: 1) defining value from the patient's perspective, 2) value stream mapping, and 3) eliminating waste in an attempt to create continuous flow. Value stream mapping was noted as the most frequently applied Lean healthcare tool. Typical implementation steps were to conduct Lean training, initiate pilot projects, and utilize interdisciplinary teams. A noted barrier was lack of applied healthcare knowledge from Lean consultants.

Young, T.P. and McClean, S.I. (2008). 'A critical look at Lean Thinking in healthcare', *Quality and Safety in Health Care*, 17(5), pp. 382-386.

This paper provided a preliminary analysis of areas where the read-across from other sectors to Lean healthcare is relatively well understood, based on a broad review of its impact on care delivery. The authors concluded that there was scope for methodological development in Lean healthcare by defining three themes associated with value—the operational, the clinical and the experiential.

Published Primary Research Articles

Primary research articles assessing health, process, satisfaction, and cost outcomes of Lean in healthcare organizations

Acute Care (Medical/Surgical)

Ellingson K., Muder R.R., Jain R. et al. (2011). 'Sustained Reduction in the Clinical Incidence of Methicillin-Resistant *Staphylococcus aureus* Colonization or Infection Associated with a Multifaceted Infection Control Intervention', *Infection Control and Hospital Epidemiology*, 32 (1), pp. 1–8.

Interrupted time-series analyses were used to assess the impact and sustainability of a multifaceted intervention to prevent methicillin-resistant *Staphylococcus aureus* (MRSA) transmission over 3 chronologically overlapping phases at 1 U.S. hospital. The researchers examined individuals admitted to acute care units between October 1, 1999 and September 30, 2008. They found that after the intervention's initiation in 2001, clinical incidence of MRSA colonization decreased, culminating in a total 61% decrease in the 7-year post-intervention period ($p=0.02$). The intervention consisted of 3 elements: 1) Lean and positive deviance change strategies to promote adherence to infection control protocol, 2) enhanced emphasis on hand hygiene and environmental disinfection, and 3) active surveillance testing of anterior nares and open wounds within 48 hours after admission to identify patients asymptotically colonized with MRSA for prompt initiation of contact precautions. The study demonstrated a significant and sustained intervention-associated reduction in hospital-wide MRSA transmission, as defined by clinical incidence of MRSA colonization or infection.

McConnell J.K., Lindrooth R.C., Wholey D.R., Maddox T.M., & Bloom N. (2015). 'Modern Management Practices and Hospital Admissions', *Health Economics*, 25(4), pp. 470-485.

This study assessed whether modern management practices such as lean and publicly reported performance measures were associated with hospital choice for acute myocardial infarction (AMI) patients. 18 cardiac care management practices were defined and measured in a survey, with 6 out of those 18 being lean practices. These practices were included in a national survey of US cardiac units

with a response rate of 46% (n = 581). The authors used a “method of multiple imputation” to account for potential non-response bias; however they noted that they could not completely rule out correlation of response with unmeasured characteristics. The American Hospital Association (AHA) Guide and Medicare’s 2009 Hospital Cost Reporting and Information System file were used to acquire hospital characteristics information.

The 2010 Medicare Provider Analysis and Review file was used to identify a sample of AMI patients over 65, who were admitted to a hospital with at least 1 other competitor within 50 miles and at least 24 annual discharges. The percentage of patients who reported “YES, they would definitely recommend the hospital” was used as a global measure for patient satisfaction. To calculate predicted AMI admissions compared to actual admissions and predicted Herfindahl-Hirschman Index, Medicare Provider Analysis and Review data were also used. Additionally, management scores were calculated by taking hospital managers’ survey scores on a 1 – 5 Likert scale and converting them into z-scores. A more positive z-score indicated better performance in that particular practice (e.g. admitting patients, measuring performance). An adjusted management score averaging the z-scores of all 18 practices was then used as the primary measure of overall management practice.

Analysis of adjusted management scores and patient admissions found that a 1 standard deviation higher management score correlated with an 8.31% higher number of AMI admissions. The largest change in admissions was positively correlated with the percentage of patients who would “definitely recommend the hospital.” Higher admission rates compared to other hospitals within the patient’s vicinity were identified as a proxy for a patient’s hospital preference. The researchers interpreted this positive association between management scores and number of admissions as follows: Management practices were correlated directly with admissions through reputational effects and indirectly through improved performance on publicly reported measures. Overall, analysis found that management scores had a statistically significant positive relationship with both AMI processes (e.g. provision of percutaneous coronary intervention within 90 minutes of arrival) and percentage of patients who would recommend the hospital.

Community Health Clinics (CHCs) & Rural Facilities

Bailey, R. (2016). *Exploring the Process of Lean Training in the Healthcare Industry*. [DBA thesis]. Walden University.

This dissertation was a qualitative single case study that sought to explore how healthcare managers successfully implemented lean training strategies to combat costs. Participants were 8 healthcare managers at a single rural care hospital in Tennessee who had implemented strategies to train staff in lean principles. For data collection, a semi-structured interview was conducted with each manager, and public hospital data and quality reports were reviewed. Yin's 5-phase qualitative data analysis process was used: Compiling the data, disassembling the data, reassembling the data, interpreting the data, and concluding the data. Themes that emerged from the author's analysis were improving quality of patient care, teamwork and collaboration, hands-on learning, and training the trainers.

Kanamori, S., Sow, S., Castro, M. et al. (2015). 'Implementation of 5S management method for lean healthcare at a health center in Senegal: a qualitative study of staff perception', *Global Health Action*, 8(1).

The authors attempted to assess the Lean 5S management method's effect on the workplace, healthcare process and outcomes, and applicability to resource-poor settings based on a pilot intervention of the 5S program in a Senegal health facility. They conducted a qualitative study by interviewing 21 health center staff members 1 year after the pilot intervention. Staff were asked about their views on the changes brought on by the 5S program in their workplace, daily routines, and services provided. Interviews were then transcribed and organized by emerging themes using thematic analysis in the coding process. The authors concluded that the 5S management method was perceived to have improved the quality of healthcare services and staff motivation in a resource-poor healthcare facility with a disorderly work environment in Senegal.

Snyder, K.D. and McDermott, M. (2009). 'A Rural Hospital Takes on Lean', *Journal for Healthcare Quality*, 31 (3), pp. 23-28.

This paper discussed the journey a 99-bed rural hospital took to integrate Lean into its organization and the outcome. The first year focused on the development of healthcare-specific Lean training modules, honing change management skills and leadership training. The hospital CEO and senior

management invited 52 personnel (a mix of managers, nurse supervisors, line staff, and business personnel) to be a part of the program. Team expectations included attendance at all workshops, participation in a Lean project, and willingness to be a trainer or mentor to future Lean teams. Senior management agreed to provide support to all team members, including time and scheduling commitment and assistance in reducing or eliminating barriers for success. Change management workshops were delivered by certified university facilitators. The hospital CEO defined 3 parameters for projects: meet the organization's strategic mission, include a 70% clinical and 30% nonclinical project mix, and involve no large requests for new money. The first Lean project aimed to decrease time spent obtaining supplies from a particular supply room from entry to exit on the morning shift by 20%. Time savings of 6 minutes, 53 seconds/supply search and annual cost savings of \$9851/year were observed. A second project aimed to reduce ED waiting times by 10% and resulted in 68 minute time savings from 230 minutes to 162 minutes after Lean. The third and last project worked to meet a standard the clinical information be documented in e-medical records within 30 minutes post-nursing assessment. Improvements resulted in reducing the average time that elapsed between taking a patient's vitals and inputting data into the EMR from a high of 538 minutes after to within 30 minutes of taking the patient's vitals. The authors found that these projects showed that similar improvements from Lean are possible within all aspects of the medical community.

Weaver A., Greeno C.G., Goughler D.H. et al. (2013). 'The impact of system level factors on treatment timeliness: utilizing the Toyota production system to implement direct intake scheduling in a semi-rural community mental health clinic', *Journal of Behavioral Health Services Research*, 40 (3), pp. 294–305.

Previous research consistently demonstrated that treatment timeliness (the amount of time between consumers' initial contact with mental health service providers and their first appointment) was an important predictor of whether consumers attended their appointments. Lean was thus evaluated as a method to change intake procedures on treatment timeliness within a semi-rural community mental health clinic. A team of administrators, clinicians, and staff conducted value stream mapping of the clinic's intake process and identified non-value added elements, potential sources of error, and waste. They then designed a new intake process based on Lean that focused on specifying the process in detail, with unambiguous connections between each step, and a simple and direct pathway. The team

found it important to understand average intake/day, times of day with heaviest intake, and months with higher intake volume in order to determine when more help was needed and how much time intake staff would have for other duties. For data analysis, 100 randomly selected cases opened the year before the change and 100 randomly selected cases opened the year after the change were examined using analysis of covariance (ANCOVA). The authors found that changing intake procedures using Lean significantly decreased the average number of days consumers waited for appointments from 11 days to 8 days ($p = .03$).

Emergency Department (ED)

Burström, L., Letterstål, A., Engström, M.L. et al. (2014). 'The patient safety culture as perceived by staff at two different emergency departments before and after introducing a flow-oriented working model with team triage and lean principles: a repeated cross-sectional study', *BMC Health Services Research*, 14, pp. 296-308.

A repeated cross-sectional study was conducted to determine the patient safety culture in a county hospital ED and a university hospital ED. The authors used the Hospital Survey On Patient Safety Culture questionnaire to assess this culture before and after a quality improvement project using Lean principles and team triage at both EDs. At the county hospital, a difference between baseline and follow-up was observed in three dimensions. For two of these dimensions, *teamwork within hospital* and *communication openness*, a higher score was measured at follow-up; *information and support to staff at adverse events* was rated lower at follow-up. At the university hospital, 3 dimensions were found as lower at follow-up: *staffing*, *information and support to patients at adverse events*, and *patient safety grade*. A higher score was measured at follow-up for *teamwork across hospital units* and *teamwork within hospital*. Overall, the authors concluded that the improvement project led to changes in self-estimated patient safety culture, with improvements in perceived teamwork and communication openness, and declines in perceived information and support to staff during adverse events.

Chan, H., Lo, S., Lee, L. et al. (2014). 'Lean techniques for the improvement of patients' flow in emergency department', *World Journal of Emergency Medicine*, 5 (1), pp. 24–28.

A quantitative, pre- and post-Lean design study was conducted to evaluate a series of Lean methods implemented to improve admission and blood result waiting times at an ED. These methods included structured re-design process, priority admission triage (PAT) program, enhanced communication with medical department, and use of new high sensitivity troponin-T (hsTnT) blood test. Triage waiting time, consultation waiting time, blood result time, admission waiting time, total processing time and ED length of stay were compared before and after implementation. After Lean implementation, the triage waiting time and end waiting time for consultation were significantly decreased. The admission waiting time to the emergency medical ward (EMW) was also significantly decreased from 54.76 minutes to 24.45 minutes after implementation of the PAT program ($P < 0.05$). The authors concluded that Lean management can improve the patient flow in ED, with adherence to lean principles being crucial to enhance high quality emergency care and patient satisfaction.

Claret P. G., Bobbia X., Olive S., Demattei C., Yan J., Cohendy R., ... & de la Coussaye J. E. (2016). 'The impact of emergency department segmentation and nursing staffing increase on inpatient mortality and management times', *BMC Health Services Research*, 16(1), pp.279-286.

This before-after study aimed to investigate the impact of a lean-based ED segmentation on patient mortality and management delays in a French university hospital. ED segmentation consisted of the development of a new patient care geographical layout on a pre-existing site and changing the organization of patient flow. Data were collected through the hospital's electronic medical record system and compared to matching seasons from the previous year to adjust for seasonal differences in mortality. A total of 83,322 patient visits were analyzed, with 61,118 before and 22,204 after segmentation. Overall, there was a significant decrease in inpatient mortality after segmentation, from 1.5% during summer 2011 to 1.3% during summer 2012 (OR = 0.85, 95% CI: 0.72,0.99).

Dickson, E.W., Anguelov, Z., Vetterick, D. et al. (2009). 'Use of Lean in the Emergency Department: A Case Series of 4 Hospitals', *Annals of Emergency Medicine*, 54 (4), pp. 504-510.

Participants in 2 academic and 2 community EDs that instituted Lean as their single process improvement strategy made observations of their behavioral changes over time. They also measured the following metrics related to patient flow, service, and growth from before and after

implementation: time from ED arrival to ED departure (length of stay), patient satisfaction, percentage of patients who left without being seen by a physician (2 EDs), the time from ordering to reading radiographs (1 ED), and changes in patient volume. The authors found that one year post-Lean, length of stay was reduced in 3 of the EDs despite an increase in patient volume in all 4. Each observed an increase of patient satisfaction lagging behind by at least a year. They additionally noted that the narratives indicate that the closer Lean implementation was to the original Toyota principles, the better the initial outcomes. The immediate results were also greater in the EDs in which the frontline workers were actively participating in the Lean-driven process changes. A factor that considerably affected the outcomes in the second and third year post-implementation was the level of continuous leadership commitment to Lean.

El Sayed, M.J., El-Eid, G.R., Saliba, M. et al. (2015). 'Improving Emergency Department Door to Doctor Time and Process Reliability: A Successful Implementation of Lean Methodology', *Medicine*, 94 (42), e1679.

This study aimed to determine the effectiveness of Lean management on improving emergency department (ED) door-to-doctor times at an academic, urban tertiary care hospital. The authors performed a before and after study at the ED after implementing a series of Lean-driven interventions over a 20-month period. A convenience sample from the pre-intervention phase (February 2012) was compared to another from the post-intervention phase (mid-October to mid-November 2013). Individual control charts were used to assess process stability. Post-intervention, a statistically significant decrease in mean door-to-doctor time (40.0 mins \pm 53.44 vs 25.3 mins \pm 15.93, $P < 0.001$) was found. Length of stay of both admitted and discharged patients dropped from 2.6 to 2.0 hours and 9.0 to 5.5 hours, respectively. All other variables including emergency department visit daily volumes, hospital occupancy, and left-without-being-seen rates were comparable.

Ford A.L., Williams J.A., Spencer M. et al. (2012). 'Reducing door-to-needle times using Toyota's Lean manufacturing principles and value stream analysis', *Stroke*, 43 (12), pp. 3395–3398.

Earlier tissue-type plasminogen activator (tPA) treatment for acute ischemic stroke was previously shown to improve the efficacy of tPA, urging national efforts to reduce door-to-needle times. To this end, the authors used Lean process improvement to develop a streamlined intravenous tPA protocol. A

multidisciplinary team conducted value stream analysis (VSA) of the acute ischemic stroke patient pathway. 132 stroke patients treated with tPA before VSA and 87 patients treated with tPA after VSA were directly compared on baseline characteristics, protocol metrics, and clinical outcomes. VSA exposed several tPA protocol inefficiencies, which were then addressed through roll-out of a new protocol designed to minimize delays. Average door-to-needle time dropped 21 minutes from 60 to 39 minutes post-VSA ($p < 0.0001$), and the % of patients treated ≤ 60 minutes from hospital arrival increased from 52% to 78% post-VSA ($p < 0.0001$), with no change in hemorrhage rates. The paper concluded that future studies should be implemented to determine whether this intervention is sustainable across various hospital settings.

Kane M., Chui K., Rimicci J., Callagy P., Hereford J., Shen S., Norris R., & Pickham D. (2015). 'Lean Manufacturing Improves Emergency Department Throughput and Patient Satisfaction', *Journal of Nursing Administration*, 45 (9), pp. 429-434.

This study involved a multidisciplinary team led by nurses and physicians who developed a plan to meet increasing demand and improve patient experience in the ED without expanding the ED's resources. An assessment and planning phase consisting of 3 meetings was conducted. Meetings were standardized and goals and objectives established to maximize effectiveness. A current state map was created that identified wait times and left-without-being-seen (LWBS) rates as key metrics to improve upon. The multidisciplinary team conducted value stream mapping, two 5S organization initiatives, three rapid process improvement workshops, and active daily management (gemba) to improve these key metrics.

The lean implementation was performed with 20 clinical staff over approximately 350 person-hours. It resulted in a 17% reduction in median length of stay (282 minutes to 243 minutes) and a 73% reduction in door-to-doctor time (49 minutes to 13 minutes). LWBS rates fell from 2% to 0.65%. The results were achieved during a period of 7% growth in throughput without increasing the size of the ED, at only a 1% growth in cost. Patient satisfaction metrics were also improved according to the Council of Teaching Hospitals' peer group percentile rankings, with "likelihood to recommend" increasing from the 12th percentile to the 75th percentile and "waiting time to see doctor" improving from the 7th

percentile to the 75th percentile. The authors concluded that lean implementation significantly decreased patient wait times and length of stay, while improving patient throughput and satisfaction.

Kelly A., Bryant M., Cox L. et al. (2007). 'Improving emergency department efficiency by patient streaming to outcomes-based teams', *Australian Health Review*, 31 (1), pp. 16-21.

A pre-post study was conducted at an emergency department (ED) at a 300-bed, community teaching hospital in Melbourne, Australia. It aimed to describe the procedure and results of a process redesign based on task analysis and Lean thinking approaches aimed at improving ED efficiency. The study compared 12-month periods before and after the process redesign for total episodes of ambulance bypass, waiting times (overall and by triage category) and total ED time (overall and by triage category). Time data were then analyzed using non-parametric methods. While the years were broadly comparable, there was an 8.4% increase in total hours of care delivered (a marker of ED workload) in the year after the change. Episodes of ambulance bypass reduced by 55% (120 v. 54). There were statistically significant waiting time reductions for triage categories 3 and 5 (median reductions 5 and 11 minutes respectively). There was an increase in total ED time for triage category 3 (median increase 7 min) and a decrease for categories 4 and 5 (median reduction 14 and 18 min, respectively). The authors concluded that process redesign using task analysis and Lean could improve ED efficiency.

Mazzocato P., Holden R.J., Brommels M. et al. (2012). 'How does Lean work in emergency care? A case study of a Lean-inspired intervention at the Astrid Lindgren Children's hospital, Stockholm, Sweden', *BMC Health Services Research*, 12 (1), pp. 28-41.

The authors aimed to address the gap in knowledge of how and why lean interventions succeed or fail. They utilized a mixed methods design to evaluate an in-depth case study of a Lean-inspired intervention in a Swedish hospital, particularly in its pediatric Accident & Emergency (A&E) Department - the largest of 3 pediatric A&Es in Stockholm. The study aimed to compare performance before and after lean intervention as well as explain how and why lean worked. The hospital's weekly average data on waiting times and patient volume were collected for 52 weeks before and 104 weeks after Lean implementation for quantitative analysis. Additionally, qualitative data from interviews and documents were retrospectively collected from the intervention-planning phase and prospectively collected during

the implementation phase. Analysis of variance (ANOVA) was used to assess differences in performance pre- and post-Lean, revealing an increase in % of patients completing their A&E visit within 4 hours from 67% to 80% [95% CI (65.5, 69.7), (78.2, 82.4)] that was maintained 2 years after the intervention. Average time to first physician consultation also decreased by 24% from 67 to 51 minutes [95% CI, (61.7, 71.5), (46.5, 56.3)] and was sustained 2 years post-Lean at 54 minutes [95% CI, (49.4, 59.2)]. The authors explained that Lean was effective because it reduced work ambiguity, created clear connections between caregivers who were dependent on each other, developed seamless and uninterrupted flow, and enabled continuous improvement through worker empowerment. Barriers to greater improvements from Lean were cited: these were job mismatch, discomfort with being monitored or with inter-professional collaboration, and some employees' distance from change-related decision-making, leading to a feeling of being inadequately informed. The authors suggested further research into which Lean changes contribute most to performance improvement, claims of contextual conditions critical to further success, and the effects of Lean on employee working conditions.

Murrell, K.L., Offerman, S.R., Kauffman, M.B. (2011). 'Applying Lean: Implementation of a Rapid Triage and Treatment System', *Western Journal of Emergency Medicine*, 12 (2), pp. 184-191.

Lean principles were used to implement emergency department (ED) process improvements in 1 U.S. hospital, leading to the development of a Rapid Triage and Treatment (RTT) system. A retrospective, observational study was then conducted comparing electronic medical record data 6 months before and after implementation to determine whether Lean principles had an effect on ED metrics. The researchers found that changes in ED processes using Lean thinking and available resources improved efficiency. Mean ED length of stay was reduced by 36 minutes and the % of patients leaving without being seen by a doctor was reduced from 4.5% to 1.5% (95% CI). Months prior to any changes, weekly process improvement meetings with front-line staff and department leadership were conducted to gain staff input and plan process changes. Value stream mapping was used to analyze the flow of patients through the ED. Non-value-adding steps were identified and then streamlined to remove waste; weekly process meetings continued after implementation to constantly re-evaluate and modify as needed. The researchers emphasized staff and physician involvement throughout the process.

Ng, D., Vail, G., Thomas, S. et al. (2010). 'Applying the Lean principles of the Toyota Production System to reduce wait times in the emergency department', *Canadian Journal of Emergency Medicine*, 12 (1), pp. 50-57.

In recognition of patient wait times, and deteriorating patient and staff satisfaction, the authors set out to improve these measures in the emergency department (ED) without adding any new funding or beds. Lean techniques such as value stream mapping, just-in-time delivery techniques, workplace organization, reduction of systemic wastes, use of the worker as the source of quality improvement, and ongoing refinement of process steps formed the basis of the project. This resulted in major improvements in departmental flow without adding any additional ED or inpatient beds. The mean registration to physician time decreased from 111 minutes to 78 minutes. The number of patients who left without being seen decreased from 7.1% to 4.3%. The length of stay (LOS) for discharged patients also decreased from a mean of 3.6 to 2.8 hours. Lastly, an improvement in ED patient satisfaction scores was noted following the implementation of Lean principles.

Vermeulen M.J., Stukel T.A., Guttman A. et al. (2014). 'Evaluation of an Emergency Department Lean process improvement program to reduce length of stay', *Annals of Emergency Medicine*, 64 (5), pp. 427–438.

Researchers sought to determine the effects of a Lean Emergency Department (ED) process improvement program on ED wait times and quality of care. They directed a retrospective cohort study of all ED visits at program and control sites during 3 waves from April 2007 to June 2011 in Ontario, Canada. The authors then conducted time series analyses comparing pre- and post-Lean implementation at program sites as well as difference-in-differences analyses comparing changes in program sites versus control sites. They found that while median ED waiting times did decrease at program sites, those benefits were diminished or disappeared when compared to control sites, which were exposed to system-wide initiatives such as public reporting and pay-for-performance. Further research was suggested to evaluate the effectiveness of Lean methods in the ED before warranting widespread use.

Intensive Care Unit (ICU)

Muder R.R., Cunningham C., McCray E., et al. (2008). 'Implementation of an industrial systems-engineering approach to reduce the incidence of methicillin-resistant *Staphylococcus aureus* infection', *Infection Control Hosp Epidemiol*, 29, pp. 702-708.

A before-after intervention study was conducted to measure the effectiveness of a Lean approach to implementing a methicillin-resistant *Staphylococcus aureus* (MRSA) prevention program. The study took place in an ICU and a surgical unit in the Pittsburgh Veterans Administration hospital and included all patients admitted to these units. The MRSA prevention program was comprised of 4 elements: 1) the use of standard precautions for all patient contact, with emphasis on hand hygiene; 2) the use of contact precautions for interactions with patients known to be infected or colonized with MRSA; 3) the use of active surveillance cultures to identify patients who were asymptotically colonized with MRSA; and 4) use of Lean to facilitate consistent and reliable adherence to the infection control program. The rate of healthcare-associated MRSA infection in the surgical unit decreased from 1.56 infections per 1,000 patient-days in the 2 years before the intervention to 0.63 infections per 1,000 patient-days in the 4 years after the intervention (a 60% reduction; $P = .003$). The rate of healthcare-associated MRSA infection in the ICU decreased from 5.45 infections per 1,000 patient-days in the 2 years before to the intervention to 1.35 infections per 1,000 patient-days in the 3 years after the intervention (a 75% reduction; $P = .001$). The combined estimate for reduction in the incidence of infection after the intervention in the 2 units was 68% (95% confidence interval, 50%-79%; $P < .001$).

Laboratory

Cankovic, M., Varney, R.C., Whiteley, L. et al. (2009). 'The Henry Ford Production System: LEAN Process Redesign Improves Service in the Molecular Diagnostic Laboratory: A Paper from the 2008 William Beaumont Hospital Symposium on Molecular Pathology', *Journal of Molecular Diagnostics: JMD*, 11 (5), pp. 390-399.

Lean was used in a molecular diagnostic laboratory to assess inefficiencies and improve speed of result generation. Baseline data analysis revealed that the greatest challenge to timely result generation occurred in the pre-analytic phase of specimen collection and transport; as such, efforts focused primarily on re-designing pre-analytic processes using Lean principles. The lab's goal was to complete greater than 90% of the molecular tests in less than 3 days. The authors stated that Lean processes

resulted in fewer steps, approaching the ideal of a one-piece flow for specimens through collection/retrieval, transport, and different aspects of the testing process. Lean created a 44% reduction in molecular test turnaround time for tissue specimens, from an average of 2.7 to 1.5 days. In addition, extending Lean principles to clinician suppliers resulted in a markedly increased number of properly collected and shipped blood specimens (from 50 to 87%). These continuous quality improvements were accomplished by empowered workers in a blame-free environment and are now being sustained with minimal management involvement.

Damato C. & Rickard D. (2015). 'Using Lean-Six Sigma to Reduce Hemolysis in the Emergency Care Center in a Collaborative Quality Improvement Project with the Hospital Laboratory', *Joint Commission Journal on Quality and Patient Safety*, 41 (3), pp. 99-107.

This before-after study conducted value stream mapping (VSM) in the emergency care center (ECC) of a health care system in a large US town. The goal was to reduce hemolysis from 9.8% to 2% in the ECC. In the VSM process, a project team of 3 laboratory managers and 2 lean-Six Sigma experts identified hemolysis as one of seven non-value-added activities in the blood collection and pre-analytical processes. They identified potential root causes of hemolysis and verified these against healthcare best practices. After identification, the team then developed a system-wide protocol involving standardized collection processes, implemented competency-based training, and improved ECC hiring practices.

Baseline hemolysis data was collected from July 2009 to December 2009, with a mean hemolysis percentage of 9.8%. Post-implementation data was collected from June 2010-September 2010, and showed a 64% reduction from baseline to 3.5%. This did not meet the hospital's goal of 2%.

After the post-implementation data collection, a collaborative pilot project was launched using PDSA cycles to confirm or negate the validity of setting a 2% goal in the ECC. A range of hemolysis levels (from a low of 0.9% to a high of 5.8%) was shown in five non-pilot pods. The two pods with full-time phlebotomists reduced hemolysis to 0.5%. From this data the team concluded that a 2% goal was attainable. As it was not economically feasible to permanently hire full-time ECC phlebotomists in all the pods, the team had phlebotomists transfer their knowledge and skills by training ECC staff (nurses and technicians) through shadowing of the phlebotomists, teach-back, and real-time practice with

immediate feedback. New hiring practices were also integrated into the ECC, requiring that multi-skilled technologists have phlebotomy training before hire and have one day of compulsory laboratory education during their orientations. Over 4 after the changes in training and hiring practices, the mean ECC hemolysis percentage was consistently <.50%.

Isaac-Renton, J.L., Chang, Y., Prystajek, N. et al. (2012). 'Use of Lean Response to Improve Pandemic Influenza Surge in Public Health Laboratories', *Emerging Infectious Diseases*, 18 (1), pp. 57–62.

Multidisciplinary response and rapid implementation of process changes based on Lean methods were used at a provincial public health laboratory in British Columbia, Canada, to improve laboratory surge capacity in the 2009 influenza H1N1 pandemic. In the face of a 10-fold increase in demand for influenza testing without approval for additional staff, the lab needed to improve efficiency by changing workflow processes. Before the onset of the pandemic, PHMRL staff had been trained in Lean methods, and many had participated in activities to enhance laboratory processes. A Lean Team comprising medical, scientific, senior, and bench-level technical staff and some administrative and support personnel was set up to apply Lean methods to the influenza laboratory workflow. They created a visually displayed value stream of all discrete steps in the lab workflow for influenza detection. Review of 'waste' steps was conducted and a kaizen session performed by lab staff, culminating in the creation of a scalable and standardized work process. Observed and computer simulating evaluation results from rapid process changes showed that use of Lean tools successfully expanded surge capacity, which enabled response to a 10-fold increase in testing demands.

Quetz J.S., Dantas I.F., Hirth C.G., Brasil C.G., & Juaçaba, S.F. (2015). 'Preliminary results of Lean method implementation in a pathology lab from Northeastern Brazil', *Brazilian Journal of Pathology and Laboratory Medicine*, 51 (1), pp. 33-38.

This case study utilized lean tools in a Brazilian medical center to improve processes in a pathology laboratory. Lean training was conducted by a team of facilitators comprised of 2 pathologists, a pharmacist, an administrator, and a receptionist. Trainings sometimes included the CEO and the entire body of employees. Value stream mapping (VSM) was then conducted, as well as spaghetti diagrams

and an A3 report. After VSM, the team implemented 'first in, first out', standardization, and continuous flow to reduce lead time from 8 – 10 days to 5 days.

It was noted that the laboratory was able to easily support an increase in number of exams in 2014 under the new system; continuous flow contributed to this by evening out demand. The authors stated that the lean implementation created a more collaborative work environment and increased worker autonomy. They noted that lean efforts depended on the CEO's support and the involvement of multidisciplinary, multi-hierarchical teams. Plan-Do-Study-Act (PDSA) cycles and visual management will be continuously used to improve processes in this laboratory.

Samuel, L., and Novak-Weekley, S. (2014). 'The Role of the Clinical Laboratory in the Future of Health Care: Lean Microbiology', *Journal of Clinical Microbiology*, 52 (6), pp. 1812–1817.

This article aimed to provide commentary on Lean's applications to microbiology labs, while discussing at length the development and results of a Lean program at the HFHS Department of Pathology and Laboratory Medicine. In 2007, the HFHS Department of Pathology and Laboratory Medicine used a Lean management approach to consolidate 4 microbiology labs into 1 lab with a projected 55 full-time staff conducting 700,000 tests annually. In using this approach, the department was able to achieve consolidation and take on additional work during the integration process, without a comparable increase in staffing. The authors concluded that Lean management practices have brought standardization, savings, and quality to many different industries; Lean management practices within the clinical microbiology laboratory could help to address the many economic, political, and medical challenges that labs face today and in the future.

Sinnott P.L., Breckenridge J.S., Helgerson P., & Arch S. (2015). 'Using Lean Management to Reduce Blood Culture Contamination', *Joint Commission Journal on Quality and Patient Safety*, 41 (1), pp.26-34.

In this pre-post study, a lean quality improvement initiative was undertaken by a US Veterans Affairs (VA) medical center to reduce its blood culture contamination (BCC) rate. A 40-hour, 1 week rapid process improvement workshop (RPIW) was conducted by representatives from hospital medicine, ED, nursing, phlebotomy, clinical microbiology, and others. The RPIW identified root causes of variation in blood culture procedures and potential improvement strategies. Changes in BCC rates were tracked

over 5.25 years (2009 - 2014, including 1.5 years before the RPIW). Additionally, results from the primary medical center were compared to data from a similar VA medical center during the same time period.

Four root causes of BCC were identified through the RPIW and refined over a 90-day period. The following countermeasures were then developed: Standardized training, certification, and recertification procedures for nurses; redesigned blood culture kit; modified order templates to default to a peripheral blood draw; wall posters with simple and clear instructions for blood draws; modified specimen labels to include standard data elements; monthly tracking and feedback of contaminated culture rates; and discontinued low-value speciation.

At baseline, annual average BCC rate at the medical center was 4.2%. In Year 1 post-RPIW, BCC rate fell to 3.4%, then to 2.8% in Year 2, and 2.4% in Year 3. BCC rate increased to 3.0% in Year 4. Each year exhibited a significant BCC reduction compared to baseline, with $p \leq .0010$ for all years. At the comparison VA site, baseline BCC rate was 4.2% and BCC change was only significant in Year 2. However, using a difference-in-difference estimation to find the effect of the lean intervention on BCC rates *independent* of the underlying BCC rate, the underlying BCC rate was 3.6%. Only Year 3's BCC rate was significantly different from the baseline underlying rate ($p=.004$, 95% CI:-0.259,-.0051). While the authors recognized that these results were disappointing, they noted that the project did reduce annual BCC rates by nearly 30% during the study period.

Sunyong M. (2004) 'Lean Management and Six Sigma yield big gains in hospitals immediate response laboratory: Quality improvement techniques save more than \$400,000', *Clinical Leadership and Management Review*, 18(5), pp.255-258.

This pre-post study evaluated a hospital laboratory's efforts to implement lean with the assistance of outside consultants. The stated goal was to reduce lab sample turn-around time with fewer staff resources. After noting that collecting all hospital samples from patients in a two-hour period created a daily bottleneck, the lab transitioned to three separate rounds of sampling, with phlebotomists required to deliver each sample to the lab directly after it was drawn. This change reportedly allowed the lab to reassign six phlebotomists, realizing savings of \$160,000 per year. Addressing the layout of

the lab itself, devices were reorganized according to the measured usage by lab staff. Finally, visual management strategies were implemented to address stock and inventory difficulties. Cabinet doors were removed and standards for automatic supply reordering were established. A reduction of 4.5 technologists resulted in savings of \$250,000 per year. In the first year of implementation overtime spending fell from \$130,000 to \$52,000, a 60% decrease. Overall savings in the first year totaled more than \$400,000. Furthermore, the authors attributed an improvement in patient satisfaction scores to the intervention (which resulted in less need to wake patients in the middle of the night).

Outpatient Care

Aij K.H., Widdershoven G., & Visse M. (2014). 'Lean Process Mapping Techniques: Improving the Care Process for Patients with Oesophageal Cancer', *Global Journal of Management and Business Research*, 14 (2), pp.81 – 98.

This case study tested the hypothesis that Lean value-stream mapping (VSM) could help streamline care for patients with esophageal cancer. The study took place in one of the largest tertiary referral center for esophageal cancer in the Netherlands. The researchers began the project by evaluating the care pathway, revealing that it was unsystematic and could lead to medical errors. Researchers then cut the number of steps needed to begin treatment from 128 to 103 and applied standardization to reduce variability. This implementation reduced the time it took for patients to start treatment from 13.5 to 10.5 weeks.

Baril C., Gascon V., Miller J., & Côté N. (2015). 'Use of a discrete-event simulation in a Kaizen event: A case study in healthcare', *European Journal of Operational Research*, 249, pp. 327-339.

The authors of this paper used a business game and discrete event simulation during a Kaizen event to simulate scenarios defined by team members in an outpatient hematology-oncology clinic. The goal was to allow a rapid and successful implementation of solutions to reduce patient lead time from registration to treatment preparation. The study began with the formation of a project team (including clinicians, managers, and academics), a project launch, and employee interviews to ensure group alignment of objectives. Process mapping of the patient pathway was then carried out for 4 different care pathways: 1) Blood sample, meet with doctor, schedule appointment, and treatment, 2) blood

sample and treatment only, 3) treatment only, and 4) meet with doctor and schedule appointment only. After more data was gathered about clinic processes, a study was conducted to gather data on the time it took for patients to reach each step in a pathway. Total lead time from registration to meeting with a doctor could only be calculated for 2 pathways: For pathway 1 total wait time was 69.31 minutes (93% of total lead time), and for pathway 4 total wait time was 48.50 minutes (97% of total lead time). These wait times were both considered too high, and reducing lead time by 45% was identified as the main objective of the Kaizen event.

Next, a business game was developed that randomly placed participants into the role of patients with differing needs (e.g., treatment type, name of doctor to meet) and had them schedule an appointment based on the patient's need. A simulation model was used that modified patient arrival rates based on the schedules generated. This allowed researchers to measure with the discrete event simulation how scheduling impacted patient wait times. The Kaizen event lasted 3 days and resulted in an action plan to implement changes, ideally in 20 working days.

The authors stated that because pathways 1 and 2 were divided over 2 days, it wasn't possible to compare results before and after testing improving propositions. Therefore only data on lead times for pathway 3 were collected 19 weeks after implementing the changes. The researchers found that patient delays before receiving treatment were reduced by 74% from 61 to 16 minutes, which was less than the simulated result of 90% reduction during Kaizen. The authors hypothesized that this gap could be explained by limits of the model not accounting for factors like patient lateness and treatments being late. The authors concluded from their findings that participants' involvement is crucial for the success of an ambitious project. They noted that use of simulation and business games can encourage participation from all members, as well as measure potential impacts of changes before implementation.

Kamiya Y., Ishijima H., Hagiwara A., Takahashi S., Ngonyani H.A.M., & Samky E. (2016). 'Evaluating the impact of continuous quality improvement methods at hospitals in Tanzania: a cluster-randomized trial', *International Journal for Quality in Health Care*. Advance online publication.

This cluster-randomized trial evaluated the impact of lean 5S on patient satisfaction in outpatient care units of 16 district-level hospitals in Tanzania. Eight district-level hospitals were randomly allocated to the intervention group and 8 hospitals to the control group. Outpatient exit surveys were conducted at all 16 hospitals at 3 time points (baseline, midpoint, and follow-up) between September 2011 and 2012: they measured cleanliness, wait times, various aspects of patient experience, and overall patient satisfaction on a Likert scale.

At baseline, no statistical difference was found for cleanliness between the intervention and control hospitals; at follow-up the intervention hospitals had higher scores than the controls with $p < 0.1$ for 4 out of 5 cleanliness variables. Waiting time also decreased significantly at midpoint and follow-up for 2 out of 4 locations (consulting room and pharmacy) within the intervention hospitals, compared to control hospitals. Waiting time differences were not significant in the outpatient department and laboratory, suggesting to the authors that it is easier to reduce lead-time in the consulting room and pharmacy. Patient experience scores were significantly higher for the intervention hospitals at midpoint, but this difference diminished at follow-up, suggesting that hospital personnel did not maintain initial improvements. Patient satisfaction scores were significantly higher for the intervention hospitals at midpoint but this difference was not significant at follow-up. The authors hypothesized that this could be due to the development of patients' higher expectations for the intervention hospitals over time, given that the exit survey asked "if the main reason a patient came to the hospital was dealt with to their satisfaction." The authors concluded that 5S implementation successfully improved hospital cleanliness, waiting time, and overall rating in the outpatient department, but that the effects on patient satisfaction were not strong. They suggested that this could be the result of the intervention's 'training of trainers' approach, whereby the success of 5S was dependent on the motivation and ability of the 'trainers.'

LaGanga L.R. (2011). 'Lean Service Operations: Reflections and New Directions for Capacity Expansion in Outpatient Clinics', *Journal of Operations Management*, 29 (5), pp. 422–433.

A Lean process improvement project was implemented that aimed to increase capacity to admit new patients into a healthcare service operation system. Analysis of 1,726 appointments in outpatient services for the year before and after the project found a 27% increase in capacity to intake new

patients and a 12% reduction in patient no-show rates as a result of changes in service processes from the improvement project.

Pharmacy

Hintzen, B.L., Knoer, S.J., Van Dyke, C.J. et al. (2009). 'Effect of lean process improvement techniques on a university hospital inpatient pharmacy', *American Journal of Health-System Pharmacy*, 66 (22), pp. 2042-2047.

The effect of Lean process improvement on an inpatient university hospital pharmacy, the University of Minnesota Medical Center (UMMC), was evaluated. Workflow in the sterile products area (SPA) was improved through the creation of accountability, standard work, and movement toward one-piece flow. Increasing the number of IV batches decreased pharmaceutical waste by 40%. Through SPA environment improvements and enhanced workload sharing, two FTE technicians from the SPA were redistributed within the department. SPA waste reduction yielded an annual saving of \$275,500. Quality and safety were also improved, as measured by reductions in missing doses, expired products, and production errors. In the inventory area, visual control was improved through the use of a double-bin system, the number of outdated drugs decreased by 20%, and medication inventory was reduced by \$50,000. Benefits of this process included an estimated annual cost saving of \$289,256 due to waste reduction, improvements in workflow, and decreased staffing requirements.

Furukawa P.O., Cunha I.C.K.O., & Pedreira M.L.G. (2016). 'Evaluation of environmentally sustainable actions in the medication process', *Revista Brasileira de Enfermagem*, 69(1), pp.16-22.

This pre-post study analyzed the ability of lean-Six Sigma to reduce waste in the medication process, by following the process from reception to pharmacy to disposal. The study was conducted at a large 446-bed hospital in Sao Paulo, Brazil from February to September 2010. An interdisciplinary team of 6 professionals from nursing, pharmacy, and environmental management participated in all stages of the project: definition, measurement, analysis, implementation, and control process.

The team began by conducting process mapping of the medication process. Problems were identified related to irrational use of resources, many medications returned and discarded at the pharmacy, and incorrect discard of waste. These problems were then ranked in terms of priority based on a *cause*

effect matrix and *effort impact matrix* to determine which issues would result in the greatest reduction of waste using the least resources. Root causes of these problems were analyzed using the 5 Why's. Then an action plan was developed based on root causes, including clear delegation of tasks and explicit deadlines.

The lean-Six Sigma intervention resulted in a 74.8% reduction in chemical, infectious, and sharps waste, a 33.3% increase in common recyclable waste, and a 20% increase in common non-recyclable waste. Based on the results, the authors concluded that the development of environmentally sustainable actions is possible in hospital settings, thereby reducing use of resources and volume of waste.

Primary & Preventive Care

Blackmore C.C., Edwards J.W., Searles C. et al. (2013). 'Nurse practitioner-staffed clinic at Virginia Mason improves care and lowers costs for women with benign breast conditions', *Health Affairs*, 32, pp. 20-26.

A breast clinic was implemented at Virginia Mason Medical Center in Seattle, Washington using Lean methods. The clinic was found to substantially improve care timeliness and efficiency for women with symptomatic benign breast conditions. Women received their final benign diagnosis in an average of four rather than 16 days, with fewer imaging studies and physician visits, when compared to a control group. Savings to the employer were estimated at \$316/patient, primarily from increased work productivity. Direct care costs decreased an estimated 19%, to \$213/patient. The authors stated that by decreasing both direct medical costs and indirect costs such as work absenteeism and presenteeism, the Virginia Mason Breast Clinic created substantial savings for providers and employers while delivering care that patients rated highly.

Hung, D., Harrison, M., Martinez, M. et al (2016). "Scaling Lean in Primary Care and Impacts on Organizational Performance", *Journal of Patient-Centered Research and Reviews*, 3 (3), pp. 206.

The authors conducted an observational study of phased Lean implementation among 328 physicians in 46 primary care departments housed within 17 geographically distinct clinic locations. Performance metrics included: workflow efficiency, productivity, operating expenses, clinical quality and patient,

physician and staff satisfaction. Interrupted time series analysis using generalized linear mixed models was used to examine lean impacts on organizational performance over time. They found that Lean implementation resulted in system-wide improvements in workflow efficiencies, physician productivity and clinical quality metrics ($P < 0.05$). Patient satisfaction with access to care, handling of personal issues and overall experience of care also increased, but decreased with respect to interactions with care providers ($P < 0.05$). Departmental operating costs decreased, though this was not statistically significant. Finally, annual staff and physician satisfaction scores increased in key domains, ranging from employee engagement and connection to purpose to relationships with staff and physician time spent working. The authors concluded that Lean system redesigns resulted in improvements on a variety of metrics ranging from provider workflow efficiencies to satisfaction among patients and staff.

Radiology

Karstoft, J., & Tarp, L. (2011). 'Is Lean Management implementable in a department of radiology?' *Insights into Imaging*, 2 (3), pp. 267–273.

Lean principles were applied in a radiology department at a very large non-profit hospital, Odense University Hospital (OUH) in Denmark. The radiology department received support from a private consultant who assessed the “hows” and “whys” of the department’s work. A multidisciplinary Lean team was formed and a clinically respected radiographer appointed as its leader. Kaizen, value stream mapping (VSM), 5S, and single minute exchange of die (SMED) were all used to increase efficiency in the department’s CT section. The tools resulted in the radiology department’s ability to examine 6 more patients during the day (900 more patients/year). Consequently, waiting lists fell dramatically across all department sections after the introduction of Lean. The authors noted that the response from the staff was positive—they had an easier overview of the day’s program, a better workflow/environment, and became focused on continuing improvement.

Lodge, A. and Bamford, D. (2008). 'New Development: Using Lean Techniques to Reduce Radiology Waiting Times', *Public Money & Management*, 28 (1), pp. 49-52.

This article reported on how systems were enhanced through the application of Lean principles within a UK hospital division of diagnostics and clinical support. The NHS Improvement Plan required that by 2008 the maximum wait from a general practitioner referring a patient, to that patient commencing definitive treatment should be 18 weeks. Early estimates in the division indicated that in order to meet this 18-week target, access to services must be in a zero- to four-week window. Lean was proposed as a mode to accomplish this. Working groups, comprising a cross-section of professional disciplines and grades, were set up with membership from across the department, division and the wider organization to understand the current performance of radiology services. The views of service users (patients and referrers) were sought, along with those of staff working in the departments in order to generate a picture of the current service provision from which to model the required changes. The working groups decided to implement an internet-based waiting list for radiology services. All radiology departments began using the internet-based waiting list module in September 2006, which since then contributed to a significant reduction in waiting times across the different imaging modalities. The longest waiting time was decreased by over 30% in all areas due to more efficient waiting list management.

Martin A.J., Hogg P., and Mackay S. (2013). 'A mixed model study evaluating Lean in the transformation of an orthopaedic radiology service', *Radiography*, 19 (1), pp. 2–6.

In this mixed model approach, researchers evaluated Lean's effectiveness as a method to improve an orthopaedic healthcare service with long waiting times and poor satisfaction among patients and staff. Data were collected before and after Lean implementation from staff and patient questionnaires, as well as from the Radiology Information System. The authors used proportionate stratified random sampling for patient data collection and a theoretical sample for staff data collection. Pre-implementation data were collected during the team's value stream mapping process, and used to plan and implement changes. Data before and after implementation were compared using Levine's test for equality of variance and a 2-sample t-test; results demonstrated that Lean resulted in better patient experiences, higher staff satisfaction, and an increase in productivity. The authors concluded that these findings supported the proposition that Lean is an effective way to improve healthcare service.

Simons P., Benders J., Bergs J., Marneffe W., & Vandijck D. (2016). 'Has Lean improved organizational decision making?', *International Journal of Health Care Quality Assurance*, 29(5), pp.536-549.

This study investigated whether a lean program changed an organization's decision-making context and made it more amenable to quality improvement initiatives. Two 25-question surveys, one in 2011 and one in 2014, were conducted with 12 professionals from a Dutch radiotherapy institute to assess their perceptions of lean in their organization and the perceived ambiguous objectives and uncertain cause-effect relations in their clinical processes. Structured interviews were analyzed using a deductive approach.

Interviewees expressed improved shared vision and decreased number of uncertain cause-effect relations. 99 positive lean effects and 18 negative lean effects were shared. Positive effects included reduced ambiguity of objectives and decreased information asymmetry in clinical process. Negative effects included conflicting objectives between research and clinical practice and unrealistic objectives. Overall, the authors found that lean implementation led to greater transparency and shared visions.

Surgery

Burkitt K.H., Mor M.K., Jain R et al. (2009). 'Toyota Production system quality improvement initiative improves perioperative antibiotic therapy', *American Journal of Managed Care*, 15(9), pp. 633-642.

A pre-post quasi-experimental study was conducted to assess the role of a Lean intervention on appropriateness of perioperative antibiotic therapy and in length of hospital stay (LOS) among surgical patients. Local and national retrospective cohorts were used. The authors used Lean methods to implement a multifaceted intervention to reduce nosocomial methicillin-resistant *Staphylococcus aureus* (MRSA) infections on a Veterans Affairs surgical unit, which led to a QI intervention targeting appropriate perioperative antibiotic prophylaxis. Appropriate perioperative antibiotic therapy was defined as selection of the recommended antibiotic agents for a duration not exceeding 24 hours from the time of the operation. The local electronic medical record system was used to identify patients undergoing the 25 most common surgical procedures and to examine changes in appropriate antibiotic therapy and LOS over time. Overall, 2550 surgical admissions were identified from the local

computerized medical records. The proportion of surgical admissions receiving appropriate perioperative antibiotics was significantly higher ($P < .01$) in 2004 after initiation of Lean (44.0%) compared with the previous 4 years (range, 23.4%-29.8%) primarily because of improvements in compliance with antibiotic therapy duration rather than appropriate antibiotic selection. There was no statistically significant decrease in LOS over time.

Collar R.M., Shuman A.G., Feiner S. et al. (2012). 'Lean management in academic surgery', *Journal of American College Surgeons*, 214 (6), pp. 928–936.

Surgical practice was identified as a specialty providing many opportunities to improve efficiency. To this end, this study evaluated Lean thinking in an academic otolaryngology operating room (OR) as a method to improve efficiency and profits, while preserving team morale and educational opportunities. An 18-month prospective 'quasi-experimental' study was used, with a multidisciplinary team systematically implementing Lean thinking. The team recorded OR turnover and turnaround time during an observer-effect period as well as after Lean implementation, and measured Lean's impact on teamwork, morale, and surgical resident education through validated surveys. During the Lean intervention period, significant decreases in turnover and turnaround time were noted (29 v. 38 minutes; $p < 0.001$ and 69 v. 89 minutes; $p < 0.001$, respectively). Composite morale scores also found improved morale after implementation ($p = 0.011$), with no effect on resident education. Lastly, financial implications of Lean found an annual opportunity revenue of \$330,000 for one OR used twice weekly. The authors noted that Lean requires cultural change through empowerment of workers to engage in continuous quality improvement, thus contradicting traditional hierarchical management. They also emphasized the importance of sustaining Lean improvements; regular meetings among key stakeholders (including management and OR employees) to review data and refine plans were used toward this end, and continued on a quarterly basis after the study.

Filho M.G., Boschi A., Rentes A.F., Thurer M., & Bertani T.M. (2015). 'Improving Hospital Performance by Use of Lean Techniques: An Action Research Project in Brazil', *Quality Engineering*, 27(2), pp.196-211.

This action research study presented the implementation of lean methods in the surgery department of a Brazilian hospital. The researchers first began by defining the scope of the project and forming an

internal team with the hospital's superintendent director as the project lead. The Material and Sterilization Center (MSC) was identified by the director as a key area of focus as it was one of the main contributors to disrupted flow and higher cost. The project's objective was to reduce cost, increase sterilization capacity, and reduce surgery delays due to lack of MSC surgical supplies. Value stream mapping was conducted and flowcharts developed for typical patient movements throughout all steps of the surgery process, beginning when the patient leaves for the hospital.

In order to reach the MSC's desired future state, 5S and visual management were used to increase efficiency, simplify processes, and reduce waste. A pull system was also used to meet demand more efficiently.

The researchers found that the lean intervention resulted in a reduction in changeover time between MSC autoclave cycles from 34 minutes to 4 minutes (88% reduction). Autoclave cycle time overall was reduced from 2 hours to 1.5 hours, resulting in a 64% capacity increase. This generated a direct cost reduction of 78%. Lastly, the pull system and increased MSC efficiency resulted in a significant 94% reduction in surgery delays.

Karvonen S., Nordback I., Elo J., Havulinna J., & Laine H.J. (2016). 'The Elimination of Transfer Distances Is an Important Part of Hospital Design', *Health Environments Research & Design Journal*. Advance online publication.

This case study used a patient flow analysis with from-to charts to influence new hospital design and layout planning at a university hospital's musculoskeletal surgery unit. The authors began by determining the main activities of the surgery unit, then studying the routes and physical movement of all patients treated in the unit over 1 year. From this data, an ideal layout of the new hospital was generated to minimize transfer distances. This was done by placing related activities near one another, based on patient flow analysis. The hospital's architectural design was then created based on the developed layout. Lastly, the authors compared current transfer distances to the distances they estimated patients would move in the new hospital.

The authors estimated that the new design would result in a 50% reduction in transfer distances for inpatients and a 30% reduction for outpatients. They concluded that a detailed patient flow analysis

with from-to charts can substantially shorten transfer distances, thereby minimizing patient transfers (a non-value-adding activity). This reduction supported productivity improvement, cross-functional teamwork, and patient safety through placement of patient flow activities close to each other.

Mazur L. M., Johnson K., Pooya P., Chadwick J., & McCreery J. (2016). 'Integrating Lean Exploration Loops Into Healthcare Facility Design: Programming Phase', *Health Environments Research & Design Journal*. Advance online publication.

This case study sought to explore what, when, and how lean can add value during the programming phase of design in a large academic hospital. The study took place during the design efforts of a surgical tower to house 19 operating rooms (ORs) as well as support spaces (e.g., pre- and post-op, central processing and distribution, materials management). Lean exploration loops (LELs) were conducted to generate evidence to support decision-making, primarily in comparing the benefits of a large footprint with few floors versus a smaller footprint with more floors and support spaces not adjacent to ORs on the same floor.

LELs quantified key operational and design features, which created opportunities to gain buy-in from stakeholders through active participation in many analyses. The authors concluded that lean was most valuable during programming when it focused on high-level operational and design issues to help establish consensus among stakeholders.

McCulloch P., Kreckler S., New S. et al. (2010). 'Effect of a "Lean" intervention to improve safety processes and outcomes on a surgical emergency unit', *The BMJ*, 341, pp. 1043–1046.

The authors investigated the effect of Lean quality improvement methods on service reliability and efficiency in an emergency general surgery ward of a university hospital in the UK. It used an interrupted time series study design and determined outcomes by measuring 7 safety relevant care processes. This was based on 969 patients admitted during the 4-month study period before Lean intervention, and 1114 patients admitted during the 4-month study period after Lean intervention was completed. The researchers found that for the 5 process measures targeted for Lean intervention, there were significant relative improvements in compliance, ranging from 28% to 149% with a p-value < 0.007. 2 processes measures were not targeted for Lean intervention and did not improve

significantly. There was also a significant reduction in new safety events after transfer to other wards ($p < 0.028$), though most adverse events were attributed to delays in investigations and treatment from factors outside of the emergency ward's control. In conclusion, the authors found that Lean can substantially improve compliance across multiple safety-related processes at the same time. They noted that given hospital care's interrelated nature, this may not translate into improvements in safety outcomes unless system-wide approaches are adopted.

Muder R.R., Cunningham C., McCray E., et al. (2008). 'Implementation of an industrial systems-engineering approach to reduce the incidence of methicillin-resistant *Staphylococcus aureus* infection', *Infection Control Hosp Epidemiol*, 29(8), pp. 702-708.

A before-after intervention study was conducted to measure the effectiveness of a Lean approach to implementing a methicillin-resistant *Staphylococcus aureus* (MRSA) prevention program. The study took place in an ICU and a surgical unit in the Pittsburgh Veterans Administration hospital and included all patients admitted to these units. The MRSA prevention program was comprised of 4 elements: 1) the use of standard precautions for all patient contact, with emphasis on hand hygiene; 2) the use of contact precautions for interactions with patients known to be infected or colonized with MRSA; 3) the use of active surveillance cultures to identify patients who were asymptotically colonized with MRSA; and 4) use of Lean to facilitate consistent and reliable adherence to the infection control program. The rate of healthcare-associated MRSA infection in the surgical unit decreased from 1.56 infections per 1,000 patient-days in the 2 years before the intervention to 0.63 infections per 1,000 patient-days in the 4 years after the intervention (a 60% reduction; $P = .003$). The rate of healthcare-associated MRSA infection in the ICU decreased from 5.45 infections per 1,000 patient-days in the 2 years before to the intervention to 1.35 infections per 1,000 patient-days in the 3 years after the intervention (a 75% reduction; $P = .001$). The combined estimate for reduction in the incidence of infection after the intervention in the 2 units was 68% (95% confidence interval, 50%-79%; $P < .001$).

Paim R., Costa A., de Carvalho J., & Costa Lima I.A. (2016). 'Lean healthcare application in a surgical procedures appointment scheduling center in a maternity', *Brazilian Journal of Operations & Production Management*, 13(4), pp.452-461.

This action research study applied lean healthcare concepts and tools in the surgical scheduling process at a network of maternity hospitals in Rio de Janeiro, Brazil. The authors conducted benchmarking visits of other Rio de Janeiro maternity wards to identify best practices, analyzed current working conditions, and compared indicators before and after the intervention. Qualitative data focused on understanding the work process was collected by observing hospital professionals and having them describe internal procedures and documents. After lean implementation, results were analyzed to identify strengths and considerations for future improvement. After implementation, the number of surgeries performed increased 15-17% in two different surgical centers. The authors concluded that better management of patient demand resulted in increased capacity utilization. Results also showed that adherence to surgery safety protocol increased by 13%, average length of stay decreased by 52%, and patient satisfaction with reception service increased by 32%.

Simons, F., Aij, K., Widdershoven, G. and Visse, M. (2014). 'Patient safety in the operating theatre: how A3 thinking can help reduce door movement', *International Journal for Quality in Health Care*, 26(4), pp. 366–371.

Previous research stressed the importance of reducing door movement during surgery to prevent surgical site infections. The authors used Lean A3 thinking to reduce door movement in one operating room for orthopedic surgery, executing an A3 report that promoted structured problem-solving based on Plan-Do-Check-Act (PDCA) cycles. A multidisciplinary team was assembled for the A3 intervention, which first defined the problem, and then investigated the current situation. They found current average door movements/hour and variations in average door movement/hour between surgeons. From these findings, the team determined a target condition for door movement, deemed as zero door movements between incision and closing of wound (except for specific clinical reasons; e.g. X-rays, unexpected materials, employee breaks, emergencies). The gap between current and target condition was then analyzed using a fish-bone diagram to identify 13 root causes of door movement in 4 categories (people, machines, methods, and materials). Actions for improvement were directed toward these 13 root causes and the effects of changes were monitored over 12 months. The intervention led to a sustained 78% decrease in door movements, bringing down the mean number of door movements/hour from 24 to 4 in the OR.

Valsangkar N.P., Eppstein A.C., Lawson A.R., & Taylor A.N. (2017). 'Effect of Lean Processes on Surgical Wait Times and in a Tertiary Care Veterans Affairs Medical Center', *Journal of the American Medical Association Surgery*, 152(1), pp.42-47.

This study examined the effect of lean processes (e.g., value stream mapping) on wait times for surgical procedures at a tertiary care Veterans Affairs (VA) medical center. Key outcome measures were wait time, clinic and telehealth volume, number of no-shows, and operative volume. The researchers utilized VA databases to assess these changes in elective general surgeries before, during, and after lean implementation. Analyses were based on paired t-tests and the total timeframe of the study was 3 fiscal years. Multidisciplinary teams participated in rapid process improvement (RPI) workshops to identify systemic inefficiencies and strategies to reduce canceled consultations, diagnostic re-work, and no-shows. High-priority triage with enhanced operating room flexibility was instituted to reduce scheduling wait times. After rollout of RPI projects, mean patient wait times decreased from 33.4 days (SD 8.3) in 2012 to 26.0 days (SD 9.5; $p = .07$) in 2013. In 2014, wait times decreased further to 12 days (SD 2.1; $p = .07$ compared to 2013). Operative volume increased from 931 patients in 2012 to 1,072 in 2014. Combined clinic, telehealth, and e-consultation encounters also increased from 3,131 in 2012 to 3,517 in 2014, while no-shows decreased from 366 in 2012 to 227 in 2014 ($p=.02$). The authors concluded based on these findings that multidisciplinary collaboration among systems can reduce systemic inefficiencies and improve patient experience.

van Vliet E.J., Sermeus W., van Gaalen C.M. et al. (2010). 'Efficacy and efficiency of a Lean cataract pathway: a comparative study', *Quality and Safety in Health Care*, 19 (6), e13.

A prospective cohort of 616 cataract patients receiving Lean care was compared to both a historical cohort of 591 patients that received traditional care and to patients waiting for Lean care in the prospective cohort. To determine efficacy, the authors analyzed how many patients received care that adhered to Lean cataract pathway specifications. To evaluate efficiency, they analyzed how often patients visited the hospital and how many additional patients were able to access the pathway. The authors found that patient visits decreased by 23% and access to the cataract pathway increased by 42%; they noted that these percentages would have been nearly twice as large if healthcare staff had adhered to Lean pathway specifications. Based on these findings, the authors emphasized the

importance of ensuring buy-in from healthcare providers to adhere consistently to Lean pathway specifications.

General

Al-Hyari K., Abu Hammour S., Abu Zaid M.K., & Haffar M. (2016). 'The impact of Lean bundles on hospital performance: does size matter?', *International Journal of Health Care Quality Assurance*, 29(8), pp.877-894.

This paper studied the effect of implementing lean tools (e.g., just-in-time, total quality management) on hospital performance in private hospitals in Jordan, and evaluated how much organization size could affect the relationship between lean tool implementation and hospital performance. The researchers analyzed the impact of lean on quality, cost, patient and staff satisfaction, and overall healthcare performance. Main lean tools (just-in-time, human resource management, and total quality management) were found to be effective in large, small, and medium-sized private hospitals without significant differences in advantages that depend on size.

Da Silva I.B., Seraphim E.C. & Agostinho O.L., Lima Jr. O.F., & Batalha G.F. (2015). 'Lean office in health organization in the Brazilian Army', *International Journal of Lean Six Sigma*, 6(1), pp.2-16.

This case study evaluated the effectiveness of lean in healthcare at a Brazilian military medical center. A hired multidisciplinary management group by the name of G5 held meetings with staff, doctors, and management to teach them lean concepts. They also conducted value stream mapping (VSM) to identify waste within the medical center. Lean techniques were conducted to achieve the waste reduction goal: future VSM, continuous flow, 5S, time reduction, and standardized work. For example, it was found that communication failures in the center's laboratory were leading to longer patient care. Non-value adding activities like these were then subject to root cause analysis and future VSM.

After conducting a climate survey of employees, the researchers found that employees' personal satisfaction increased from 30% before lean implementation to 70% after lean implementation. The authors also found that after lean implementation, the medical center's rank rose to 2nd place out of 21 medical centers in Brazil.

Drotz, E. and Poksinska, B. (2014). 'Lean in healthcare from employees' perspectives', *Journal of Organization and Management*, 28 (2), pp. 177-195.

This paper aimed to contribute toward a deeper understanding of the new roles, responsibilities, and job characteristics of employees in Lean healthcare organizations. The paper was based on 3 cases studies of healthcare organizations that were regarded as successful examples of Lean healthcare applications. Data were collected by methods including interviews, observations, and document studies. The authors found that Lean caused organizational focus to shift from healthcare professionals, where clinical autonomy and professional skills were the guiding principles, to process improvement and teamwork. They noted that different job characteristics may make it difficult to implement certain Lean practices in healthcare. Teamwork and decentralization of authority were given as examples of Lean practices that could be considered counter-cultural because of healthcare's strong professional culture and uneven power distribution, with doctors as dominant decision makers.

Ferguson A., Aaronson B., & Anuradhika A. (2016). 'Inbox Messaging: an effective tool for minimizing non-urgent paging related interruptions in hospital medicine provider workflow', *BMJ Quality Improvement Reports*, 5(1), advance online publication.

This study used lean to reduce pages for non-urgent communication, in order to minimize workflow interruptions at Virginia Mason Hospital. To facilitate the implementation, a workgroup was formed consisting of unit-based leaders, nurses, providers, administrators, and IT staff. A baseline measurement of paging data was conducted over a 2-week period, facilitated by an RN project manager and hospital leader. Inbox messaging was then identified by the workgroup as a tool that could provide back-and-forth messaging without audible interruptive alerts. This method was chosen due to its success as a tool in Virginia Mason's ambulatory setting. Multiple PDSA cycles were then implemented to fine tune the messaging intervention. Immediately after implementation, inbox messages increased from 0 to 80, and non-urgent pages decreased from 103 to 38 ($p < .001$). The total number of communications also increased after the intervention from 116 to 131 ($p < .001$). The authors concluded that the inbox messaging tool was successful in reducing the number of non-urgent, interruptive pages from hospital RNs to hospital medicine providers.

Goodridge, D., Westhorp, G., Rotter, T. et al. (2015). 'Lean and leadership practices: development of an initial realist program theory', *BMC Health Services Research*, 15 (1), pp. 362-377.

The authors attempted to address the questions: "What changes in leadership practices are associated with the implementation of Lean?" and "When leadership practices change, how do the changed practices contribute to subsequent outcomes?" using a qualitative, multi-step approach. They collected data through a key informant consultation, a stakeholder workshop, documentary review, 26 audiotaped and transcribed interviews with health region personnel, and team discussions. These data yielded seven initial hypotheses, finding that Lean: 1) aligns the aims and objectives of health regions; 2) permits attention and resources to quality improvement and change management; 3) provides an integrated set of tools for particular tasks; 4) changes leaders' attitudes or beliefs about appropriate leadership and management behaviors; 5) demands increased levels of expertise, accountability, and commitment from leaders; 6) measures and uses data effectively to identify actual and relevant local problems and root causes of those problems; and 7) creates/supports a 'learning organization' culture.

Holden, R.J., Eriksson, A., Andreasson, J. et al. (2015). 'Healthcare workers' perceptions of lean: A context-sensitive, mixed-methods study in three Swedish hospitals', *Applied Ergonomics*, 47, pp. 181-192.

This article looked into two key areas for further Lean research: 1) the effect of contextual factors on Lean, and 2) healthcare workers' perceptions of Lean. The authors specifically addressed how hospital workers' perceptions of Lean implementation varied across contexts. Standardized surveys were completed by RNs and physicians across hospital units (N=236, 57% response rate). The study found that employees' perceptions varied by hospital, and that employees in higher-acuity units reported more favorable perceptions of Lean. The study also found that nurses reported more favorable perceptions than physicians.

Jimmerson, C., Weber, D., and Sobek, D.K. (2005). 'Reducing Waste and Errors: Piloting Lean Principles at Intermountain Healthcare', *The Joint Commission Journal on Quality and Patient Safety*, 31 (5), pp. 249-257.

Lean tools, specifically value stream maps (VSMs) and A3 reports were used in a pilot project at Intermountain Healthcare to improve efficiencies. Participants made many improvements, ranging

from simple changes implemented immediately (for example, heart monitor paper not available when a patient presented with a dysrhythmia) to larger projects involving patient or information flow issues across multiple departments. Most of the improvements required little or no investment and reduced significant amounts of wasted time for front-line workers. In one unit, turnaround time for pathologist reports from an anatomical pathology lab was reduced from 5 to 2 days.

Kanamori S., Castro M.C., Sow S., Matsuno R., Cissokho A., & Jimba M. (2016). 'Impact of the Japanese 5S management method on patients' and caretakers' satisfaction: a quasi-experimental study in Senegal', *Global Health Action*. Advance online publication.

This pre-post controlled study implemented 5S in 10 health centers in Senegal and analyzed its impact on client (patient and caretaker) satisfaction. A 5S 'pretest' was first conducted at a trial facility to establish a reference health center as well as test and validate 5S training instruments. Then pre-5S implementation data was collected at 4 facilities selected for implementation and 4 control facilities. From September – December 2012, this data was gathered in the form of questionnaires given to clients with 10 five-point Likert items to measure client satisfaction. From May – June 2013, data was collected again at all 8 facilities post-5S implementation and an impact assessment was conducted. After the second data collection, 5S intervention was also conducted at the 4 control facilities and 1 non-study facility.

In regression analysis, 5S implementation was associated with a significant increase in client satisfaction scores. At baseline, the mean overall client satisfaction score was 4.01 (SD = 0.51) in control facilities and 3.98 (SD = 0.59) in intervention facilities. At follow-up, satisfaction increased to 4.07 (SD = 0.51) in the control facilities and 4.20 (SD = 0.59) in the intervention facilities. The authors concluded that 5S has potential to improve satisfaction in resource-poor health facilities, although it does not directly address resource problems.

Khlie, K., Serrou, D. & Abouabdellah, A., (2016). 'The impact of Lean-logistics and the information system on the information flow management within the healthcare supply chain'. In *Intelligent Systems: Theories and Applications (SITA), 2016 11th International Conference*, pp.1-5.

This case study focused on the impact of lean on information management performance and cost within a 10-hospital system in Morocco. The case study consisted of 1) identification of waste, 2) evaluation of waste, and 3) performance measurement. To identify waste, interviews were conducted with various healthcare professionals (e.g., pharmacists, managers, physicians) in several departments. These interviews led to identification of problems in 3 main categories: organizational problems, lack of a sufficient relevant information system (e.g., inaccurate or lacking information), and lack of sufficient tools to track performance (e.g., in HR utilization rates). Focusing on the last two categories, the researchers implemented a healthcare information system (HIS) and developed a dashboard to measure the impact. A working group was formed with 4 coordinators, 3 industrial engineering researchers, 4 organizational science experts, and pharmacists. The team collected 6 months of historical data on waste identified by lean, and logistic costs associated with the lack of an HIS. Examples of waste were expiration costs, stock shortage costs, and HR underutilization. To evaluate the data on waste, the researchers compared the 6 months of data before HIS implementation to 6 months of data after HIS implementation. Lastly, in regards to performance measurement, the researchers used a balanced scorecard to develop a dashboard evaluating expiration costs, stock shortage costs, and HR underutilization costs before and after implementation of lean HIS. The authors found that on all 3 measures of costs (expiration, stock shortage, HR underutilization), costs were lower after HIS implementation. They concluded that integrating HIS infrastructure is one of the most important dimensions of improving information management, and that lean implementation within the HIS reduced costs for the hospital system.

Sampalli, T., Desy, M., Dhir, M. et al. (2015). 'Improving wait times to care for individuals with multi-morbidities and complex conditions using value stream mapping', *International Journal of Health Policy and Management*, 4 (7), pp. 459–466.

Over an 18-month time period, healthcare staff applied a patient-centric approach that included Lean methodology of Value Stream Mapping (VSM) to improve wait times to care. The evaluation framework was grounded in the needs and perspectives of patients and individuals waiting to receive care. Patient-centric views were obtained through surveys such as Patient Assessment of Chronic Illness Care (PACIC) and process engineering-based questions. In addition, Lean VSM was added to

identify non-value added processes contributing to wait times. From this process, the care team successfully reduced wait times to 2 months in 2014 with no wait times for care anticipated in 2015. Increased patient engagement and satisfaction were also noted. In addition, successful transformations and implementation resulted in resource efficiencies without cost increases. The authors stated that patients showed significant improvements in functional health after intervention.

Portioli-Staudacher, A. (2008). 'Lean Healthcare: An Experience in Italy', *Lean Business Systems and Beyond*, 257, pp. 485-492.

The results of a Lean implementation at an Italian hospital were presented, stemming from a need to cut cost and reduce inventory. A large reduction in inventory was achieved, and broken processes leading to excessive inventories were identified to remove the problem's root causes. Finally, hospital staff was taught to think differently about materials management activities: rather than by batching (e.g. ordering 3 weeks' worth of a medicine at once), better and faster results were achieved by standardizing activities and managing orders and activities throughout the week (e.g. ordering medicines every day to replace those consumed).

White M., Wells J.S., and Butterworth T. (2014). 'The impact of a large-scale quality improvement programme on work engagement: Preliminary results from a national cross-sectional-survey of the 'Productive Ward'', *International Journal of Nursing Studies*, 51 (12), pp. 1634-1643.

This paper examined the impact of a large-scale Lean Quality Improvement program, the 'Productive Ward', on work engagement of involved nurses and ward teams in the UK. Using the Utrecht Work Engagement Scale (UWES), the authors surveyed, measured, and analyzed work engagement in a representative test group of hospital-based ward teams who had recently commenced the latest phase of the national 'Productive Ward' initiative in Ireland and compared them to a control group of similar size and matched (as far as is possible) on variables such as ward size, employment grade and clinical specialty area. 338 individual datasets were recorded, n = 180 (53.6%) from the Productive Ward group, and n = 158 (46.4%) from the control group; the overall response rate was 67%, and did not differ significantly between the Productive Ward and control groups. The work engagement mean score (\pm standard deviation) in the Productive group was 4.33(\pm 0.88), and 4.07(\pm 1.06) in the control

group, representing a modest but statistically significant between-group difference ($p = 0.013$, independent samples t-test). Similarly modest differences were observed in all three dimensions of the work engagement construct. Employment grade and the clinical specialty area were also significantly related to the work engagement score ($p < 0.001$, general linear model) and (for the most part), to its components, with both clerical and nurse manager grades, and the elderly specialist areas, exhibiting substantially higher scores. The authors concluded that their findings demonstrate how Lean QI activities appear to positively impact work engagement of ward-based teams.

Other

Kimsey, D.B. (2010). 'Lean methodology in health care', *AORN*, 92 (1), pp. 53-60.

A rapid improvement team at Lehigh Valley Health Network, Allentown, Pennsylvania, implemented a plan, do, check, act cycle to determine problems in the central sterile processing department, test solutions, and document improved processes. By using A3 thinking, a consensus building process that graphically depicts the current state, the target state, and the gaps between the two, the team worked to improve efficiency and safety, and to decrease costs. Gap analysis was conducted to examine the initial and future state of the staff's tool sterilization cycle. By eliminating jack jams and increasing drying temperature to the expected level, staff increased capacity by 30%. Additionally, after repairing and calibrating tools, staff members were able to eliminate the flash cycle portion of the sterilization cycle, saving 10 hours of work per day. The sterile processing team and senior leaders found that non-preventive maintenance calls decreased from 6 per month to 2. The cost of non-preventive maintenance decreased from \$12,000 per month to \$3,600 per month. The average use of the equipment increased from 60% to 90%, and the use of a responsibility plan for routine inspection and maintenance of equipment increased from 0% to 90%. The end result was cancellation of a unit upgrade because it was no longer needed.

Primary research articles identifying components, methods, barriers, and facilitators for implementing Lean in healthcare organizations

Cardiology

Ulhasan W., Sandahl C.P., Westerlund HP et al. (2013). 'Antecedents and characteristics of Lean thinking implementation in a Swedish Hospital: a case study'. *Quality Management in Health Care*, 22 (1), pp. 48–61.

This case study investigated a cardiology department's experience from initial adoption to adaptation of Lean thinking. It sought to determine how the department - which had a long history of quality improvement - decided to introduce Lean, and how Lean impacted employees' work. The authors used semi-structured interviews, non-participant observations, and document studies to gather this information. They then conducted content analysis of the data, finding that the department's previous improvement efforts may have facilitated the introduction of Lean thinking. This history was not as important in predicting the sustained usage of Lean over time. Additionally, individual differences in staff members' perceived need for change led to varying degrees of Lean adoption. For successful Lean implementation, the authors found work re-design and teamwork beneficial to improving patient care. Similarly, problem solving was deemed helpful in maintaining staff engagement and thus sustained improvements.

Community Health Clinics (CHCs) & Rural Facilities

Carter, P.M., Desmond, J.S., Akanbobnaab, C. et al. (2012). 'Optimizing Clinical Operations as part of a Global Emergency Medicine Initiative in Kumasi, Ghana: Application of Lean Manufacturing Principals to Low Resource Health Systems', *Academic Emergency Medicine*, 19 (3), pp. 338–347.

This study aimed to describe the application of Lean to improve clinical operations at Komfo Anokye Teaching Hospital in Ghana, while identifying key lessons learned to aid future global improvement initiatives. A 3-week Lean improvement program focused on the admissions process at the hospital was completed by a 14-person team in six stages: problem definition, scope of project planning, value stream mapping, root cause analysis, future state planning, and implementation planning. Additionally,

8 lessons learned from the initiative were identified: 1) the Lean process aided in building a partnership with Ghanaian colleagues; 2) obtaining and maintaining senior institutional support was necessary and challenging; 3) addressing power differences among the team to obtain feedback from all team members was critical to successful Lean analysis; 4) choosing a manageable initial project was critical to influence long-term Lean use in a new environment; 5) data intensive Lean tools could be adapted and were effective in a less-resourced health system; 6) several Lean tools focused on team problem-solving techniques worked well in a low-resource system without modification; 7) using Lean highlighted that important changes do not require an influx of resources; 8) despite different levels of resources, root causes of system inefficiencies were often similar across healthcare systems, but require unique solutions appropriate to the clinical setting.

Emergency Department (ED)

Naik T., Duroseau Y., Zehtabchi S. et al. (2012). 'A structured approach to transforming a large Public Hospital Emergency Department via Lean methodologies', *Journal for Healthcare Quality*, 34 (2), pp. 86–97.

The authors outlined a systemic method to apply Lean principles across the entire emergency department (ED) patient experience to transform a high volume ED in 1 hospital. They then compared ED performance metrics before and after Lean implementation, finding that median and IQR results showed improvement on several metrics after implementation. The hospital partnered with a Lean consulting firm, established an executive Lean steering committee that ranked True North metrics for the hospital's improvement vision, and then determined major value streams based on their contribution to True North metrics. The ED was identified as a key value driver and selected as 1 of 4 service lines for initial Lean intervention. At the emergency department level, an ED Lean steering committee was created and trained in a 2-day Lean introduction program. The committee consisted of departmental leadership and other key stakeholders, such as representatives from finance and hospital operations. The steering committee participated in a 3-day value stream analysis to map out implementation over the first year. Rapid Improvement Events (RIEs) were held monthly, and enlisted an 8 – 12 member team of front-line staff (e.g. MDs, RNs, support staff) with varying degrees of relationship to the process of focus, providing diverse perspectives. A facilitator experienced in Lean

principles guided the team, and a member with intimate knowledge of the process (often a director/manager) was assigned as 'process owner,' with oversight of implementation/sustainment. A new standard workflow and responsibilities were then immediately shared with front-line staff following RIEs. Visible executive commitment at all levels was noted as critical to successful Lean transformation.

Intensive Care Unit (ICU)

Bastian N.D., Munoz D., & Ventura M. (2016). 'A Mixed-Methods Research Framework for Healthcare Process Improvement', *Journal of Pediatric Nursing*, 31, pp.39-51.

This paper applied a mixed-methods research framework incorporating lean thinking to a pediatric intensive care unit (PICU) at Penn State Hershey Children's Hospital. The researchers sought to identify if this methodology could lead to better healthcare process improvement implementation when assessing the current state of workflow in the PICU. The framework consisted of three phases: 1) stakeholder analysis, 2a) staff survey, 2b) time-motion study, and 3) process improvement. In phase 1 of the case study, researchers held two separate meetings: one with two physicians and the other with two nurses in the PICU. This allowed the PICU stakeholders to walk through various workflow elements they did not previously consider important. After interviews, the researchers observed nurses' and physicians' activities in the PICU as part of an observational study, to examine issues previously identified in the interviews as well as identify other causes of inefficiency.

In phase 2a, the researchers conducted a survey of physicians and nurses in the PICU focused on workflow efficiency and clinician satisfaction issues. This survey allowed the researchers to identify perceived critical to quality elements for measuring work performance, including satisfaction of patients' families, patient safety, efficient use of resources and time, and job satisfaction.

Phase 2b was a time-motion study during which clinicians collected data on time spent on daily workflow activities. This time-motion study assessed the appropriateness and time decomposition of workflow processes, while further identifying critical workflow activities.

Phase 3, process improvement, used the main findings from phase 2b to address four main categories impacting clinical efficiency and satisfaction: communication, layout, procedures/standards, and health information technology. Fishbone diagrams were used for both root cause analysis (RCA) and to generate recommendations for process improvement.

Overall, the study found that implementing the framework led to identification and categorization of different workflow tasks and activities into both value-added and non-value added in an effort to provide more valuable and higher quality patient care. The researchers emphasized that involvement of healthcare stakeholders, namely nurses and physicians, was critical to fully understanding PICU workflow and discovering root causes of inefficiencies.

Pharmacy

Al-Araidah, O., Momani, A., and Khasawneh, M. et al. (2009). 'Lead-Time Reduction Utilizing Lean Tools Applied to Healthcare: The Inpatient Pharmacy at a Local Hospital', *Journal for Healthcare Quality*, 32 (1), pp. 59-66.

The authors applied selected principles of Lean management to reduce time associated with drug dispensing at an inpatient pharmacy at a local hospital. Thorough investigation of the drug dispensing process revealed unnecessary complexities leading to delays in medication delivery. DMAIC (Define, Measure, Analyze, Improve, Control) and 5S (Sort, Set-in-order, Shine, Standardize, Sustain) were used to identify and reduce waste that increased the lead-time in healthcare operations at the pharmacy under study. The study's results revealed potential savings of >45% in drug dispensing cycle time.

Primary & Preventive Care

Grove, A.L., Meredith, J.O., Macintyre, M. et al. (2010). 'Lean implementation in primary care health visiting services in National Health Service UK', *Quality and Safety in Health Care*, 19 (5), e43.

Findings were presented on a 13-month Lean implementation in National Health Service (NHS) primary care health visiting (HV) services from May 2008 to June 2009. A Lean Thinking project team was established which included staff and management from a variety of roles related to the HV service, without formalized roles or project champions. This team took part in 8 workshops throughout the

project to share ideas and learn from one another, and were assisted by Lean consultants. Stakeholder and value stream mapping (VSM) was used to determine essential tasks in health visiting services and links between relevant stakeholders. Through discussion with these stakeholders, waste processes were identified and new process maps were produced. Quantitative data were provided through a 10-day time-and-motion study of a selected number of staff. Analysis of VSM processes revealed that 67% of 67 identified processes were waste; the revised process map reduced this to 23 process steps. One notable example of improved processes was a change to methods of contacting central administration. Initially, administrative staff would wait for large quantities of documents to accumulate before dispatching them in weekly batches to central administration; this led to extended waits for patient appointments and increased stress to employees due to uneven workloads. To improve this process, the Lean Thinking team introduced more document envelopes that could be dispatched daily, thus eliminating uneven workloads from batching of documents and shortening the average wait for a new appointment from 1 week to 2 days. The study concluded that a large amount of waste could be eliminated through simplification and standardisation of day-to-day tasks, without the need for expensive or time-consuming organisational changes. The authors noted that members of the Lean team continue to make small improvements in their respective areas, but that changes in organizational culture and management practice will be required to provide a supportive environment for change. Management support across the entire organization was also cited as necessary to sustain and introduce future Lean initiatives.

Gray, C., Martinez, M., and Hung, D. (2014). 'PS1-29: Changing the Culture of Medicine: An Exploration of Lean Healthcare in Primary Care', *Clinical Medicine & Research*, 12 (1-2), pp. 98–99.

This study qualitatively evaluated a Lean implementation at a large healthcare organization. Researchers conducted observations of key implementation events and interviewed frontline leaders, as well as physicians, nurses, and medical assistants who participated in the change effort. The data produced from these qualitative methods were analyzed and coded using an inductive, grounded approach. The paper highlighted five main changes that produced cultural conflict when this healthcare organization implemented Lean. They were 1) adopting team care approaches, 2) democratization of the workplace and the erosion of hierarchies, 3) reducing variation and

standardizing work, 4) surveillance of staff and employees, and 5) a perceived emphasis on profit over patient care. The authors concluded that implementing new ways of delivering care in healthcare organizations is often met with many challenges. Some of these challenges may be rooted in a conflict between new sets of cultural values and those that have historically existed in the field of medicine. Reconciling these conflicts may be one of the most difficult challenges healthcare organizations face as they try to implement wide- scale change.

Grove, A.L., Meredith, J.O., Macintyre, M. et al. (2010). 'UK health visiting: challenges faced during lean implementation', *Leadership in Health Services*, 23 (3), pp. 204-218.

The paper presented challenges identified during a lean implementation in a health visiting service within a large primary care trust in NHS UK. A triangulated approach to data collection was used to determine the root cause of challenges faced during lean implementation. The 3 methods were selected for qualitative analysis were semi-structured interviews, document analyses, and researcher participant observation. From these methods, 6 key challenges were identified: 1) high process variability, 2) a lack of understanding of lean, 3) poor communication and leadership, 4) target focused implementation, 5) problems defining waste, and 6) difficulty in defining the customer and what the customer values.

Hung D., Martinez M., Yakir M., & Gray C. (2015). 'Implementing a Lean Management System in Primary Care: Facilitators and Barriers From the Front Lines', *Quality Management in Healthcare Journal*, 24(3), pp.103-108.

This case study was conducted to highlight key facilitators and barriers to implementing lean among frontline primary care physicians (PCPs). It took place at a large California ambulatory care delivery system serving 1 million patients. In-depth interviews were conducted with PCPs, staff, and administrators to identify key factors affecting lean re-designs in primary care.

Aspects identified as critical when introducing lean were staff engagement and performance management, sensitivity to the professional values and culture of medicine, and perceived adequacy of organizational resources. Drivers of change were staff empowerment at all levels, visual display of performance metrics, and a culture of innovation and collaboration. Identified barriers were physician resistance to standardized work, difficulty transferring management responsibilities to non-physician

staff, and time and staffing required to participate in improvement efforts. The authors concluded that understanding early facilitators and barriers can maximize lean's potential to improve health care delivery.

Hung, D., Gray, C., Martinez, M. et al. (2016). 'Acceptance of Lean redesigns in primary care: A contextual analysis', *Health Care Management Review*, advance online publication.

This study aimed to identify contextual factors that were most critical to implementing and scaling Lean redesigns in all primary care clinics of a large ambulatory care system. The authors conducted over 100 interviews and focus groups with frontline physicians, clinical staff, and operational leaders. Data analysis was then conducted using a modified Consolidated Framework for Implementation Research, called CFIR-PR. Several domains identified through CFIR-PR were vital to acceptance of Lean redesigns. In the implementation process, acceptance was influenced by time and intensity of exposure to changes, top-down versus bottom-up implementations, and degree of employee engagement in developing new workflows. Important factors of the inner setting were the clinic's culture and style of leadership, and availability of information on Lean's effectiveness. Lastly, individual and team characteristics regarding changed work roles, and related issues of professional identity, authority, and autonomy were important.

Surgery

van Rossum L., Aij K.H., Simons F.E., van der Eng N., & Ten Hav W.D. (2016). 'Lean healthcare from a change management perspective: the role of leadership and workforce flexibility in an operating theatre', *Journal of Health Organization and Management*, 30(3), pp.475-493.

This cross-sectional survey was conducted in the operating theatre (OT) of a Dutch University Medical Centre to evaluate the influence of organizational factors on a hospital's capacity for lean change. Transformational leadership was expected to ensure top-down implementation of lean, while researchers hypothesized that team leadership would also influence the necessary bottom-up commitment of employees. Further, it was expected that greater workforce flexibility would result in increased lean implementation through adapting organizational elements and optimizing process flow.

The cross-sectional survey was conducted in the OT 18 months after lean implementation in the department. Employees (n = 380) were asked to complete a 69-item survey that was distributed by e-mail. After 2 weeks, a reminder to complete the survey was sent to those who had not responded/had responded incompletely. The overall response rate was 27% (103/380 employees). The authors stated that the respondents reflected the general OT 'population' as they were distributed evenly across functions.

Linear regression analysis was conducted to test the hypotheses; it was found that all three predictors together explain 53% of the difference in how lean healthcare implementation is perceived ($p < .0001$). Each individual predictor also had a significant positive relationship to its respective dependent variable. Workforce flexibility had the strongest relationship with lean implementation, though the strength of the association was similar for all three predictors. The authors concluded that transformational leadership, team leadership, and workforce flexibility were facilitators of lean transformation in an operating theatre.

General

Aij, K.H., Simons, F.E., Widdershoven, G.A.M. et al. (2013). 'Experiences of leaders in the implementation of Lean in a teaching hospital—barriers and facilitators in clinical practices: a qualitative study', *BMJ Open*, 3 (10), e003605.

This study aimed to systematically investigate the experiences of leaders in the implementation of Lean within a teaching hospital in the Netherlands. Authors conducted semi-structured, in-depth interviews of 31 medical, surgical and nursing professionals with an average of 19.2 years of supervisory experience. All professionals were appointed to a Lean Training Program and were directly involved in the implementation of Lean. Based on interview results, the researchers found that leadership management support, a continuous learning environment, and cross-departmental cooperation were seen as significant for successful Lean implementation. The results suggested that a Lean Training Program contributed to positive outcomes in personal and professional skills that were evident during the first 4 months after program completion.

Andersen, H. and Rovik, K.A. (2015). 'Lost in translation: a case-study of the travel of lean thinking in a hospital', *BMC Health Services Research*, 15(1), pp. 401-410.

The paper explore the 'travel' of Lean within a Norway hospital by assessing local actors' Lean perceptions through their images of factors for successful Lean intervention. These perceptions described the characteristics of Lean in use. Perceptions were collected through focus group interviews with three groups of stakeholders: managers, internal consultants and staff. A questionnaire was used to reveal the factors' relative importance. Identified important factors for Lean's success matched the literature, except that external expert change agents were not perceived to promote Lean. New factors were also added. Two-thirds of the most important identified factors were novel, local ones. Among these were a 'problem' rather than 'method' focus, a bottom-up approach, internal consultants, credibility, realism, and patience. Local actors had different images of Lean depending on their hierarchical level. The authors concluded that ideas of Lean were transformed more than once within the hospital.

Ballé, M. and Régnier, A. (2007). "Lean as a learning system in a hospital ward", *Leadership in Health Services*, 20 (1), pp. 33-41.

Lean was applied in a hospital ward by nursing staff, who identified a number of complex nursing issues, such as medication distribution errors, catheter infections, nosocomial infections, bedsores. 5S was implemented in storage areas in order to move supplies out of ward corridors and keep corridors clear for safety reasons. Nursing practices were also standardized, resulting in the rate of incidents per patients being reduced by 45% over 2 years. The nursing manager additionally reported that her greatest satisfaction from the Lean process was perceived noticeable improvement in nurse-patient relationships.

Brandao de Souza, L. and Pidd, M. (2011). 'Exploring the barriers to Lean health care implementation', *Public Money & Management*, 31 (1), pp. 59-66.

This work analyzed implementation barriers in the UK National Health Service's (NHS) application of Lean healthcare principles. It concluded that with slight modifications for the healthcare industry, Lean

thinking can achieve good results. The authors conducted their analysis based on interviews with directors, managers, and healthcare practitioners as well as their own experiences implementing Lean at the NHS. The first major barrier identified was provider concerns that Lean treats patients as uniform 'parts'; clarification and evidence must be provided to show otherwise. Additional identified barriers were professional and functional silos, organizational hierarchies, and shifting managerial focus from temporary to permanent solutions. In addressing the former two issues, non-hierarchical multidisciplinary teams must be established to ensure unbiased performance improvement across departments. For the latter matter, managers may be trained to make decisions using evidence-based analysis. To prevent the undesirable side effects of using performance measures to quantify Lean's impact, implementation teams should be involved in defining their own metrics, and Lean terminology should be standardized to prevent miscommunication. Overall, it was found that provider empowerment and clear structure should be emphasized for Lean implementation to be successful.

Burgess, N. and Radnor, Z. (2013). 'Evaluating Lean in healthcare', *International Journal of Health Care Quality Assurance*, 26 (3), pp. 220-235.

The authors presented observations on Lean implementation in UK hospitals based on content analyses of all annual reports and websites for said hospitals over two time periods. They found that Lean implementation overall tends to be isolated to a few projects within organizations, and that across hospitals there exists a spectrum of implementation levels ranging from tentative to systemic. Time-series data noted an increase in Lean usage and system-wide Lean approaches over time. The paper concludes that further analysis is needed to document the effects of organizational context on Lean approaches used and the sustainability of said approaches.

Chiarini A. & Baccarani, C. (2016). 'TQM and lean strategy deployment in Italian hospitals,' *Leadership in Health Services*, 29(4), pp.377-391.

This article analyzed the deployment path of lean-TQM implementation in Italian public healthcare to assess benefits and pitfalls. 3 case studies were conducted in 3 large Italian hospitals with 500+ beds each. All 3 hospitals had embraced lean or TQM as part of their strategic objectives. The case studies were based on interviews with 4 managers across the 3 hospitals, who were chosen because they had

managed several lean-TQM projects previously and were experienced with many different organizational problems. The research team developed an interview guide with open-ended questions that was used in a semi-structured interview format. Examples of questions were "what tools were used [in lean implementation]?", "what did you think of these tools?", and "would you give me an example of what you think about it?" The authors then grouped interview responses based on patterns and repeated elements.

The researchers found that there was a specific deployment path for TQM-lean implementation, and that implementation was linked to increased patient satisfaction and organizational performance. Some barriers that could affect TQM-lean effectiveness were problems with senior management commitment, staff management, manufacturing culture, and tools adaptation.

Eiro, N.Y., & Torres-Junior, A.S. (2015). 'Comparative study: TQ and Lean Production ownership models in health services', *Revista Latino-Americana de Enfermagem*, 23 (5), pp. 846–854.

Eiro and Torres-Junior compared the application of Total Quality (TQ) and Lean models in healthcare through a descriptive case study in Brazil. TQ and Lean were compared at a large medical diagnostic service and a medium-sized private hospital that had implemented Lean before. The study found that Lean was better suited for people that work systemically and generate flow, leading to increased adherence to standard work as well as continuous improvement and staff involvement in problem-solving. The TQ model was found to be more widespread, and to involve more bureaucratic procedures that were continuously audited and required more stable control.

Esain, A., Williams, S. and Massey, L. (2008). 'Combining Planned and Emergent Change in a Healthcare Lean Transformation', *Public Money & Management*, 28 (1), pp. 21-26.

A longitudinal study was employed to evaluate the implications of planned and emergent change when deploying 5S Lean at a UK NHS Trust that employed approximately 13,000 staff serving a population of around 600,000 at multiple locations. Formal interviews were conducted with 4 hospital personnel/managers who acted as Lean change agents, a questionnaire was employed that collected data on successes and problems in implementation, and observations were recorded during meetings

and workshops. All of the change agents were supportive of 5S, but indicated there were limitations. They thought the tool should not be seen as a vehicle for major change but, rather, as a starting point. It was suggested that 5S is an integral part of wider strategic change management program.

Harrison M.I., Paez K., Carman K.L., Stephens J., Smeeding L., Devers K.J., & Garfinkel S. (2016). 'Effects of organizational context on Lean implementation in five hospital systems', *Health Care Management Review*, 41(2), pp.127-144.

This case study consisted of semi-structured interviews at 5 healthcare organizations to evaluate the effects of intra-organizational context on 12 lean rapid improvement projects at these organizations. All of the projects sought to improve clinical care delivery. A framework of factors likely to affect lean quality improvement (QI) was developed based on literature and utilized in developing interview questions. Interviews were then transcribed and given qualitative codes. Available documents, data, and observations were utilized as supplements to the interviews. Case studies were constructed for lean implementation in each organization; these case studies and the 12 projects were compared across organizations.

Based on data from the sources above, the researchers identified intra-organizational characteristics affecting organization-wide lean projects, and also often shaping project outcomes. Higher levels of these characteristics were associated with better project outcomes. The characteristics were listed as follows: 1) CEO's active support and commitment to lean, 2) prior organizational capacity for QI initiatives, 3) alignments of lean initiatives with organizational mission, 4) dedication of resources and experts to lean, 5) staff training before and during projects, 6) establishment of measurable and relevant project targets, 7) planning of project sequences that enhance staff capabilities and commitment without overburdening them, and 8) ensuring communication between project members and other affected staff. The authors concluded that their study underscores the importance of ensuring that organizational infrastructure can support an improvement initiative.

Jorma T. & Tiirinki H. (2016). 'LEAN thinking in Finnish healthcare', *Leadership in Health Services*, 29(1), pp.9-36.

This study used a mixed-methods survey approach to evaluate the use and associated outcomes of lean in the Finnish public healthcare system. A 28-question survey with both qualitative and quantitative questions was sent to Finnish public healthcare workers between February and June 2014, and received a 44.4% response rate (110 out of 248). 79 respondents indicated that their organization had at least one ongoing lean initiative focused on patient or care processes. 100% of respondents ranked developing healthcare processes as either “very important” or “important.” Only 3 out of 110 respondents indicated that they did not know what lean meant and were subsequently excluded from the rest of the survey. In general, there was high awareness of lean methods; for example, among respondents who had no ongoing lean initiatives focused on patient or care processes (n = 28), 84% reported that they had considered launching a lean project in their organization. While there was high awareness of lean, the authors found that lean was a new concept to Finnish healthcare and that it had not been implemented deeply. Lean was mostly used as a development tool for financial savings and improved efficiency. Implementations had not been systematic, data was lacking, and most lean initiatives documented were started less than five years ago. However, respondents’ experiences with lean were encouraging, as 100% of those who had implemented lean initiatives defined them as successful.

Kinder, T. and Burgoyne, T. (2013). ‘Information Processing and the Challenges Facing Lean Healthcare’, *Financial Accountability & Management*, 29 (3), pp. 271-290.

The authors suggested that the level of information required by Lean projects was beyond the capacity of many NHS trusts, and used Galbraith’s information processing theory as a mode of explanation for why many NHS Lean healthcare projects failed. They concluded that, if generalizable, their findings challenge the premise that Lean can be used to deliver sustainable cost reduction while improving quality of care. On a micro-level, the paper cited lack of clinician support and rejection of the ‘cuts’ ideology as reasons for failed Lean implementation. The paper focused on information processing management as a mechanism to examine how the complexity and uncertainty of healthcare affected Lean implementation. It found that most Lean initiatives involved less than 20% of staff, and ‘rapid improvement events’ (RIEs) rather than long-term systemic applications. Other studies were cited stating issues with Lean implementation such as silos of Lean usage, lack of staff training and

opportunities for experimentation, and overly long time to complete projects. The authors looked at two Lean implementation projects and conducted interviews with 3 project participants, 2 team leaders, and the Deputy Chief Executive using a prepared survey. They deemed that Lean and all other change projects are 'information-hungry'. Lacking information processing systems make their sustained success difficult. Inadequate information processing, low senior clinician engagement, and absence of commitment-based HR were seen as difficulties for Lean RIEs.

Lee J.Y., McFadden K.L., & Gowen C.R. (2016). 'An exploratory analysis for Lean and Six Sigma implementation in hospitals: Together is better?', *Health Care Management Review*. Advance online publication.

This survey of U.S. hospitals sought to explore existing patterns of lean-Six Sigma implementation and compare performance of the different patterns. Survey questions included measurements developed from lean-Six Sigma healthcare research following a literature review. A geographically stratified sample of 307 hospitals was selected from an online hospital database, and a total of 215 responded to the survey (70%). The survey was completed by organizational managers most likely to have acute knowledge of lean-Six Sigma: chief quality officers, patient safety directors, risk management officials, and nursing directors.

Using factor analysis, the authors identified 2 clusters based on type of lean implementation: a Moderate Six Sigma group (Cluster 1) and a lean-Six Sigma group (Cluster 2). Cluster 1 (n = 116) represented hospitals that implemented Six Sigma at a moderate level but used little to no lean implementation. The authors claimed that this might imply the use of project-based Six Sigma approaches without using lean to manage internal processes on a daily basis for continuous improvement. Cluster 2 (n = 99) represented hospitals that embraced both lean and Six Sigma activities for continuous improvement. Hospitals in this cluster exhibited a much higher level of lean and Six Sigma implementation, with lean's holistic, whole-system view appearing to result in higher performance in responsiveness capability and patient safety. The authors noted an interesting finding from this study that no cluster was obtained for hospitals using only lean. This indicated that implementing lean without Six Sigma was not a predominant implementation strategy in U.S. hospitals. Based on the higher performance in Cluster 2, the authors found there was justification to use more lean tools in combination with Six Sigma for better outcomes.

Radnor, Z., Holweg, M. and Waring, J. (2012). 'Lean in healthcare: The unfilled promise?', *Social Science & Medicine*, 74 (3), pp. 364-371.

This paper reported on 4 Lean implementation case studies in the UK National Health Service (NHS). Similar to others, it found that implementation often involved Lean 'tools' such as rapid improvement events (RIEs) that led to localized improvements. Contextual differences between Lean healthcare and manufacturing were cited: first, patients' status as both customers and commissioners of care in the private sector, which impacts how customer value is defined; second, the healthcare industry's design as 'capacity-led', which limits the ability to influence demand and utilize freed-up resources. If not addressed, these differences could severely limit Lean's impact on healthcare. The authors interviewed senior, middle management, and front-line NHS employees. They assessed implementation on 4 dimensions: 1) Lean's definition, 2) activities undertaken, 3) organizational readiness, and 4) sustainability of process improvements. The study found that the definition of 'customer' and customer value was often variable and not clearly ascertained, leading to improvements guessing at what customers wanted that were not necessarily aligned or even compatible across care pathways. It also deemed that, similar to in manufacturing, there must be a shift from tool-based to continuous improvement approaches for widespread, sustained productivity gains to be achieved.

Ul Hassan, W., Ulrica von Thiele, S., Thor, J. et al. (2014). 'Interactions between lean management and the psychosocial work environment in a hospital setting – a multi-method study', *BMC Health Services Research*, 14, pp. 480-491.

This work aimed to ascertain the effects of Lean on the psychosocial work environment. As such, psychosocial work environment was measured twice with the Copenhagen Psychosocial Questionnaire (COPSOQ) employee survey during Lean implementations on May-June 2010 (T1) (n = 129) and November-December 2011 (T2) (n = 131) at three hospital units (an Emergency Department (ED), Ward-I and Ward-II). Information based on qualitative data analysis of the Lean implementations and context from a previous paper was used to predict expected change patterns in the psychosocial work environment from T1 to T2 and subsequently compared with COPSOQ-data through linear regression analysis. Between T1 and T2, qualitative information showed a well-organized and steady Lean implementation on Ward-I with active employee participation, a partial Lean implementation on Ward-

II with employees not seeing a clear need for such an intervention, and deterioration in already implemented Lean activities at ED, due to the declining interest of top management. Quantitative data analysis showed a significant relationship between the expected and actual results regarding changes in the psychosocial work environment. Ward-I showed major improvements especially related to job control and social support, ED showed a major decline with some exceptions while Ward-II also showed improvements similar to Ward-I. The study's results suggested that Lean may have a positive impact on the psychosocial work environment when properly implemented, and that deterioration of Lean work may correlate with deterioration of psychosocial work environment. The authors also noted that employee involvement in Lean change processes may minimize any potential harmful psychosocial effects from Lean intervention.

Primary Research on Lean Tool Development, Testing, and Validation in Healthcare

Intensive Care Unit (ICU)

Almoosa K.F., Luther K., Resar R., & Patel B. (2016). 'Applying the New Institute for Healthcare Improvement Inpatient Waste Tool to Identify 'Waste' in the Intensive Care Unit', *Journal for Healthcare Quality*, 38(5), pp.e29-e38.

The authors of this paper attempted to apply a new Institute for Healthcare Improvement (IHI) tool to measure the prevalence of and reason for inappropriate use of intensive care unit (ICU) beds. Unnecessary days (waste) in a 16-bed closed medical ICU (MICU) and a 10-bed semi-closed transplant surgical ICU (TSICU) were identified by physicians over a 3-month period. Data was collected on 513 patients admitted to both ICUs for a total of 1,631 patient-days. This data demonstrated that 15% of MICU days and 25.8% of TSICU days were unnecessary. Common causes of delays were transfer of patients out of the ICU, end-of-life decision-making, and delays in procedures. However, determination of waste varied widely among physicians, ranging from 4.5% to 27.7% in the MICU and 0% to 37.5% in the TSICU. Therefore, although limited by variations in physician perceptions, the tool may be helpful in identifying specific causes of delays in the ICU that could be the focus of improvement efforts. Based on their findings, the authors also suggested that waste is likely common in the ICU and warrants further attention.

Surgery

Lasorsa I., Liuzzi G., Calabrese R., & Accardo A. (2015). An Innovative Method for Standardizing Lean Management Approach in Hospitals. In *16th Nordic-Baltic Conference on Biomedical Engineering*, pp. 67-70. Springer International Publishing.

This case study tested a new method for standardizing lean healthcare management in the operating theatre (OT) of an Italian hospital; it specifically focused on improving the process of providing surgical tools for operations. Preliminary, informal interviews were first conducted with clinicians and nurses,

and some selected to be part of the lean team based on their personal interest. This team then set out to reduce seven forms of waste in the surgical tool value chain, as identified by Goal Question Metric (GQM), a data measurement and metric identification tool originally used in computer science. 15 questions and 17 metrics were defined to identify the root causes of waste in the process. A value stream map (VSM) was designed that separated activities into stages: Stage 1 – preparation of tools on the surgical cart in the OR, Stage 2 – utilization of surgical tools, Stage 3 – positioning of instruments in the surgical cart for transport to the Central Sterile Supply Department (CSSD), and Stage 4 – transport to the Central Sterile Supply Department. Data was collected on all 4 of these stages.

Based on data collected, it was found that 71.2% of activities in Stage 1 of the surgical tool process added value. In Stage 1 and Stage 3, percent of non-conformities to standard procedures was 47.8% and 75% of the process respectively. The team used these findings to create a future stream map, which was simulated and potential economic savings calculated. The potential economic savings was €229,421. The authors concluded that the teams' proposal of improved inventory of surgical tools and new classification of tools in containers could potentially increase the number of available surgical tools, reduce the number of tools that need to be transported to the CSSD, and generate economic savings.

General

Castle A. & Harvey R. (2009). 'Lean information management: the use of observational data in health care', *International Journal of Productivity and Performance Management*, 58(3), pp.280-299.

This paper compared traditional data collection methodologies in healthcare to observational methods closely aligned with lean thinking. The authors conducted case studies on the use of observational data in the UK National Health Service (NHS), and then used their evaluations to drive general principals regarding the application of observational data in healthcare.

One such case study was conducted in the sterile services department of a general hospital, which was perceived as responsible for delaying operations. The sterile services department felt that these problems were the result of insufficient staffing to meet demand. The authors worked with this

department and the hospital's surgery operating theatres over two months to examine processes and improve workflow, using video to record the process of packing several different sets of instruments. Analysis of video resulted in identification of waste (namely insufficient number of scanners/printers and inefficient location of said printers), which led to the development of solutions to eliminate waste (e.g., equipment purchase and workspace redesign). These solutions rendered the recruitment of 6 extra staff members unnecessary.

Overall, the authors stated that the case studies resulted in fundamental changes in processes by observing the current processes in a way that staff could relate to. They also found that having frontline staff in charge of collecting data made the need for change and urgency of the situation more apparent. In conclusion, the authors found that the observational data methodology was valid in a range of clinical settings for examining a process to identify opportunities for improvement.

Henrique D.B., Rentes A.F., Filho M.G., & Esposto K.F. (2016). 'A new value stream mapping approach for healthcare environments', *Production Planning & Control*, 27(1), pp. 24-48.

This article presents a new lean value stream mapping (VSM) approach specifically geared toward healthcare environments, as opposed to current healthcare VSM models that adapt manufacturing-style VSM. The authors' proposed VSM model analyzes activities in relation to their effect on treatment time, with the intention of uniting the positive aspects of various mapping methodologies found in healthcare literature. The novel VSM model was implemented in a Brazilian hospital to observe its effect on processes and related patient lead times.

Results showed that the novel VSM model was able to identify some operational bottlenecks and waste that the authors stated could not be identified by other mapping models studied; they determined that these un-identified bottlenecks had a combined impact of 110 days, or 56%, of patients' waiting time. However, the researchers did not test these other mapping models against the novel VSM model directly. The authors concluded that through this novel VSM model, all flows that impact patient lead time can be shown on a single map, with clear visualization of patients' actions and support activities.

Wallace J. & Savitz L. (2007). 'Estimating waste in frontline health care worker activities', *Journal of Evaluation in Clinical Practice*, 14(1), pp. 178-180.

As part of an AHRQ funded study intended to provide hospitals with estimates of waste, researchers at Intermountain Healthcare and Abbot Associates examined waste estimates for hospital frontline worker activity. Researchers used time-and-motion study design to observe staff activities for 72 hours at two tertiary referral centers and three community hospitals. The time-and-motion design records data on the length and location of actors' different actions using a stopwatch or video recording. 61 staff members were observed, with 69% classified as caregiver roles and 31% classified as technical. 43% of observed staff were nurses.

During 1-2 hour observation periods, observed group activity was classified into 1 of 6 classes. These classes were operations, defects/errors, classifying activities, processing activities, motion, and other. Classes were created using Toyota Production System, separating activities by value and non-value adding activities. Frequency of interruption, location changes, and problems identified by staff post-observation were documented in field notes. Statistically significant reliability estimates (intraclass correlations) were computed by comparing the principal observer's observation data with simultaneous, independently collected observations from 8 different observers, resulting in intraclass correlations between .67 and .88 ($p < .054$ to $.007$).

Operations, the class defined as having no waste, took up 41% of total observation time. Activities considered 100% waste (defects/errors & other) comprised only 3% of observed time. Clarifying, processing, motion, and other were assigned as low, medium, or high waste based on the observed proportion of recoverable waste time: 20% indicated Low, 50% indicated Medium, and 80% indicated High. Half of total documented waste was reported as part of the High range according to these parameters. Researchers used base salary and fringe benefits to calculate a cost of waste per hour ranging from \$7.40 to \$18.98. Interruptions and location changes occurred at average rates of 8 and 13 instances per hour, respectively, both with an SD of +/- 11 interruptions. The most common problems reported by staff during post-observation interviews were supply/equipment related problems (36%), missing information (22%), and redundant work (17%). The researchers concluded that their results indicate a need for increased attention to operational quality.