BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-037667
Article Type:	Original research
Date Submitted by the Author:	19-Feb-2020
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Keywords:	Organisation of health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Quality in health care < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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A systems approach to health service design, delivery and improvement: A systematic review and meta-analysis

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Key words

Systems approach, Systematic Review, Quality improvement, Healthcare design, Health systems engineering

Word count: 3,240; **Reference count**: 83

Abstract

Objectives

To systematically synthesise the evidence-base for a systems approach to healthcare design, delivery or improvement.

Design

Systematic review and meta-analysis

Methods

We systematically reviewed published literature for comparative studies in healthcare improvement grounded in a systems approach (for protocol see PROSPERO CRD42017065920). We searched Medline, Embase, HMIC, Health Business Elite, Web of Science, Scopus, PsycINFO and CINAHL from inception until 28th May 2019 for relevant studies. These were screened and data extracted independently and in duplicate. We excluded studies without clear evidence of a systems approach being used and without control or quantitative outcome data. Study outcomes were heterogeneous, and stratified by whether they reported patient and/or service outcomes. Meta-analysis was conducted with Revman software version 5.3 using odds ratios - heterogeneity was assessed using I^2 statistics.

Results

Of 11,405 records 35 studies were included of which 28 (80%) were before-and-after design only, five were both before-and-after and concurrent design, and two were RCTs. There was wide variation in reported outcomes. Exploratory meta-analysis of before-and-after studies suggested favourable effects on both patient outcomes (n=13, OR=0.52 (95%CI 0.38 to 0.71) I^2 = 91%), and service outcomes (n=17, OR=0.40 (95%CI 0.31 to 0.52) I^2 = 97%).

Conclusions

This study suggests that the use of a systems approach to healthcare improvement results in a statistically significant improvement to both patient and service outcomes. However, the current literature is sparse, often of poor quality and is highly heterogeneous.

Strengths and limitations of this study

- This is the first systematic review to provide a comprehensive and transparent synthesis of the published evidence-base for a systems approach to healthcare improvement.
- The benefits to patient and service outcomes are demonstrated across widely differing health settings and, medical disciplines.
- There was heterogeneity in the literature and the studies included, with wide variation in the settings, participants, comparators, follow-up durations, and study designs.

Introduction

The 20th and 21st centuries have witnessed the development of highly effective healthcare technologies, diagnoses and interventions.[1,2] Nonetheless, there remains a pressing need for improvement in both the quality and safety of care delivery.[3–5] This is often attributed to several factors including multimorbidity,[6] the complexity of healthcare delivery,[7] and a variety of cultural and organisational challenges[8,9]. Drawing on the experience of fields such as engineering and design a "systems approach" to improvement has been advocated, that recognises the interacting components of healthcare delivery, the people involved, as well as planned, considered and adaptive iterative implementation.[10–16] However, there has not been a systematic review of the evidence-base for such an approach within the healthcare literature to date.

Modern healthcare systems are striving for integrated, patient-centred, effective, and efficient care[17] but the lesson from engineering is that such systems do not happen by accident; they need to be planned, designed, and built. [18] Understanding what this process might look like has been explored with reference to the literature on Patient Safety,[19] Human Factors and Ergonomics (HFE),[20] General Practice,[21] the wellbeing of healthcare workers[22] and Public Health.[23] These reviews, while useful, are limited in their scope and employ narrow views of a systems approach.

The primary objective of this study is to review, comprehensively, the usefulness of a systems approach to healthcare improvement. There were no limits on language, participant types, outcome types or any particular healthcare domain.

Definition of a systems approach

Defining a systems approach is challenging. The approach has origins in a variety of disciplines, which have both diverged and converged over the past century. These range from mathematics to social science, and span both the physical and biological sciences.[24] In order to arrive at a definition that we could operationalise for the purpose of this systematic review, the team reviewed definitions of a systems approach including Clarkson et al.,[10] Maier and Rechtin,[25] Chen[26] and the NASA systems engineering handbook[27]. As a result, we developed a shared understanding of a system, at its fundamental level, as:

A collection of different elements (or things) which together produce results unachievable by the individual elements on their own.[28]

Our working definition of a systems approach, which has been informed by Clarkson et al.[10], is as follows:

A systems approach to healthcare improvement is a way of addressing health delivery challenges that recognises the multiplicity of elements interacting to impact an outcome of interest and implements processes or tools in a holistic way.

This view of a systems approach integrates perspectives on people, systems, design and risk in a way that is applicable to healthcare systems across all scales from local service systems through to organisational, cross-organisational and national policy levels.

Methods

This systematic review and meta-analysis was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard[29]. The complete PRISMA checklist is included in the supplementary materials.

Following a preliminary review of the Cochrane systematic review database and the PROSPERO database of ongoing reviews, we developed and registered a protocol for this systematic review (PROSPERO CRD42017065920).

Information sources and inclusion criteria

We searched the following databases with no limits on date of publication: Medline, Embase and HMIC (via OVID), Health Business Elite, PsycINFO and CINAHL (via EBSCO), Web of Science and Scopus. The search was first conducted in August 2017 and repeated on 28th May 2019. There were no limits on language, participant types, outcome types or any particular healthcare domain. Studies had to present numerical results of primary research and have a control group, which could be concurrent or historical. The full search strategy including specific search strings are provided in supplementary file 1.

Study selection process

We used a structured, two-stage, approach to determine inclusion. The first stage involved a title/abstract review of citations after removing duplicates. The second consisted of a full text review of the 107 papers identified as potential for inclusion.

For the title/abstract review stage, three pairs of researchers looked at a third of the records each. Studies were selected for inclusion or rejection independently by each researcher, and with differences resolved first within the pair, and then within the whole team where the pair could not agree.

The full text review stage applied the definition of a system and of a systems approach as stated above. Researcher pairs individually reviewed studies for inclusion or exclusion based on the following two questions:

1. Does the study identify a clear problem framed in a systems context and demonstrate the use of a systems approach, in some way? AND
2. Does the study have an appropriate design to address the research question?

Question one excluded any study which did not in some way demonstrate a systems approach in its formulation and/or implementation of an improvement intervention, while question two excluded all protocols, conference abstracts, systematic reviews, reviews, editorials and any paper with no primary research or no comparator arm.

Following the individual assessment, members of each pair discussed their results to arrive at a consensus on which studies to include. We provide the full list of excluded studies with reasons for exclusion in supplementary file 2.

Data collection

A template for data extraction was developed by the research team working through samples of the selected papers to identify relevant fields and tables appropriate to the study question. The data extraction process was designed to include an element of quality control and minimisation of researcher bias. The lead author initially extracted data from all included studies using the agreed template, with other team members each assigned a subset of these to independently corroborate.

Data were extracted into seven tables as listed below and included in supplementary file 3:

a) Study design, baseline type, blinding and funding source
b) Patient outcomes for studies with before and after design

c) Patient outcomes for studies with concurrent design
d) Service outcomes for studies with before and after design
e) Service outcomes for studies with concurrent design
f) Study source, year and scoring of system aspects
g) Quality assessment of all included studies against CASP checklist

Patient and Public Involvement (PPI)

Due to the focus of this review on synthesising evidence within the academic literature the involvement of PPI was not applicable.

Data analysis

Study analysis was performed in two stages. First, a qualitative synthesis of the evidence using a best-fit framework synthesis,[30,31] and second, a quantitative meta-analysis of studies with sufficient data.

Qualitative analysis was performed using ATLAS.ti Qualitative Data Analysis (v8.4.2 © 2013-2018 ATLAS.ti Scientific Software Development GmbH). Review manager (version 5.3, The Cochrane Library) was used for the meta-analyses using a random effects model due to the heterogeneity of participants, interventions and outcome measures for patient and service outcomes. Meta-analysis was conducted where three or more studies reported outcomes in the same category. Categories were before-and-after studies versus studies with concurrent controls, continuous versus categorical versus time-to-event data and service versus patient outcomes. Heterogeneity was assessed using the I^2 statistic, using standard thresholds. Risk of publication bias was assessed by use of a funnel plot.

Risk of bias for all studies was assessed by two researchers independently using the Critical Appraisal Skills Program (CASP) checklist[32]. Differences were resolved through a consensus process. The CASP checklist for cohort studies, case control and RCTs were applied accordingly. The checklists consist of eleven or twelve questions in three sections – Study validity, study results and local value of results.

Results

Our initial search found 11,463 records published prior to August 2017 and an extended search in May 2019 found a further 3,081 records. After deduplication there were 11,405 citations including two records added from personal sources. Of these, 11,298 records were excluded after the scanning process, leaving 107 full texts. Included were 35 studies, out of which 23 provided sufficient data for the five meta-analyses conducted (Figure 1).

Of the 35 included studies, 28 (80%) had a before-and-after design only. Six studies had both a before-and-after and concurrent design (including one with Cluster Randomised Control) and one was an RCT. The full characteristics of included studies are presented in Table 1. Excluded full text studies, with reasons for exclusion are in the online supplemental content.

The qualitative synthesis highlighted the diversity in the approaches taken in the various studies and key success factors from the authors' perspectives. Diversity in approaches may be categorised in three ways:

1. A comprehensive implementation of traditional tools and approaches such as PDSA, Lean, Human Factors Engineering, WHO health systems strengthening principles, SEIPS model, Business Process Re-engineering, Structure- Process- Outcome (SPO) and various combinations of these.[33–46]

2. A focus on the breadth of coverage of the intervention, involving a wide range of stakeholders from patients, communities, multiple departments including consideration of physical structures.[47–61]
3. The application of standard systems concepts such as systems thinking and complex adaptive systems theory.[62–66]

Table 1: Characteristics of included studies

Study	Population	Study type	Follow up duration	Participants		Outcomes
				Before	After	
Afsar-manesh et al.[67]	Staff and patients	Before & After	18 months	NR	NR	Patient
Allaudeen et al.[44]	Emergency Department patients and staff	Before & After/ Concurrent control	3 years	NR	NR	Service
Anderson et al.[49]	Geriatrics patients and staff	Before & After	17 months	154	117	Patient /Service
Bell et al.[50]	Pregnant women	Before & After	4 months	NR	NR	Patient/Service
Bhatt et al.[47]	Nursing staff	Before & After	17 days	13	17	Service
Bhutani et al.[48]	Babies discharged as healthy patients' parents, paediatricians, paediatric nurses, home care nurse agencies	Before & After	12 months	3,227 8,186	8,186 11,995	Patient Service
Bowen et al.[51]	Stroke patients	Before & After	32 days	75	88	Service
Bradley et al.[54]	Primary care patients	Before & After	18 months	140	140	Service
Catchpole et al.[34]	Trauma patients	Before & After	5 months	14 72	13 107	Service
Chandrasekar et al.[38]	All medical inpatients at a single UK hospital	Before & After	34 months	NR	NR	Patient/Service
Cochran et al.[45]	Patients, nurses and a team of ER and system engineering specialists	Before & After	8 months	NR	NR	Patient/Service
DeFlitch et al.[46]	Patients and staff	Before & After	3 years	NR	NR	Patient/ Service
Dennerlein et al.[55]	Direct patient care workers	Before & After	12 months	2149 2348	2131 2414	Service
Gupta et al.[35]	Healthcare staff and patients	Before & After	6 months	36	28	Service
Hathout et al.[56]	Healthcare staff	Before & After	18 months	NR	NR	Patient/ Service
Heymann et al.[57]	Healthcare staff	Before & After	14 months	1000	1000	Service
Hultman et al.[36]	Healthcare staff and patients	Before & After	24 months	39 (27)	46	Patient/ Service
Huntington et al.[39]	Women's health teams	Before & After/Concurrent control	4 years	16,535 NR	15,789 NR	Patient Service
Hwang et al.[68]	Cardiac patients	Before & After	12 months	182 282	282 182	Patient Service
Kane et al.[66]	Nursing bed managers, transfer line operators, patient pathway coordinators	Before & After	Can't tell	NR	NR	Service
Khan et al.[52]	Patients, parents or caregivers, nurses, medical students and residents	Before & After	3 months	947 1574	890 1532	Patient
Kottke et al.[62]	CHD patients	Before & After	6 months	529 529	511 511	Patient Service
Lick et al.[59]	Cardiac arrest patients	Before & After	6 months	247 247	106 106	Patient Service
Loh et al.[69]	Cataract surgery patients	Before & After	6 months	6,111	39,390	Service
McGrath et al.[65]	Patients and staff including nurses, nurse assistants, occupational therapists, physical therapists, physicians	Before & After/Concurrent control	5 months	557	678	Service
McKetta et al.[63]	Cardiac centre staff	Before & After	4 months	135	138	Service
Moran et al.[53]	Population of England and wales	Before & After	4years	44059 41149	17956 17092	Patient Service
New et al.[41]	Theatre staff	Before & After/Concurrent control	6 months	450 25	567 17	Patient Service
Rateb et al.[70]	HIO doctors, nurses, admin staff, customers	Before & After	Can't tell	251 101	251 101	Patient Service
Rothemich et al.[71]	Adult smokers, family physicians,	Concurrent control	1 month	958	857	Service
Rustagi et al.[43]	Healthcare staff and patients	Before & After/Concurrent control	9 months	17	18	Patient

Ryan et al.[61]	Detox service users	Before & After	Can't tell	171	2,754	Patient
Shultz et al.[72]	Physicians and staff	Before & After/Concurrent control	2 years	67,914	67,914	Service
Srinivasan et al.[37]	1 -23 month old babies and parents	Before & After	3 weeks	221 114 86	91 115 97	Patient/ Service
Tetuan et al.[64]	Nurses	Before & After	12 months	1652	1998	Service

A full qualitative synthesis is beyond the scope this review. However, a significant number of the success factors reported are related to people. This was expressed in the form of engaging with stakeholders, taking a team-based approach, enhancing communication, adopting a collaborative approach, patient-centeredness and physician-centeredness. Similarly, difficulty in measuring impact and the inability to generalise to other contexts emerged as the most significant limitations. These findings, together with the observation that the majority of studies have a before-and-after design (instead of RCTs) present a challenge in relation to what is usually considered good quality evidence.

Five exploratory meta-analyses were conducted; two on patient outcomes (presenting categorical outcomes reported in before-and-after studies (Figure 2), and concurrent control studies (Figure 3)) and three on service and resource use outcomes (presenting categorical (Figure 4) and continuous outcomes (Figure 5) for before-and-after, and concurrent control design (Figure 6) study results separately). Heterogeneity was high in all meta-analyses.

Exploratory meta-analysis suggests that systems approaches significantly improve both service use and patient outcomes in before-and-after studies, whereas studies with concurrent controls did not show statistically significant results. Results for continuous data outcomes were consistent with those for categorical data outcomes. Heterogeneity was very high in all except one meta-analysis, which had three included studies. The funnel plot (Figure 7) is unclear regarding publication bias. If anything, it might suggest that small studies with very positive results are missing, rather than those with null results.

We included two RCTs in our meta-analysis. Both reported significant improvements in outcomes favouring a systems approach. Rustagi et al.[43] randomised 36 health facilities in Cote d'Ivoire, Kenya and Mozambique to usual care or "a systems engineering intervention" stratified by country and volume. They found that antiretroviral (ARV) coverage for HIV positive women increased 3-fold in intervention facilities compared to control facilities whilst HIV-Exposed Infants (HEI) screening increased 17-fold. Similarly, Rothemich et al.[60] randomised 16 practices into intervention (8) and control (8) groups to determine whether a systems approach enhances smoking cessation support in primary care practices. The study concluded that a systems approach to identifying smokers, advising, assessing readiness to quit and referral to supporting agencies, led to statistically significant increases in cessation for patients irrespective of gender, compared to traditional tobacco-use vital sign screening alone.

It is important that the above results are interpreted with the quality of the included studies in mind. We used the CASP appraisal tools to assess the extent to which individual study results might deviate from the truth because of how the study was conducted. Focusing on the CASP questions for which two researchers agreed a study was satisfactory, the two included RCTs both scored 8 each out of 9. The five studies with concurrent varied from 7 out of 10 to 10 out of 10. Before-and-after studies which made up 80% of included studies varied widely in quality, ranging from 1 out of 12 to 12 out of 12. Details of the results are included in the data extraction tables in the supplementary materials.

Discussion

Our meta-analyses suggest that the use of a systems approach to improving care results in significant benefits for both patient and service outcomes in all the subgroups analysed. These included two Randomised Controlled Trials (RCTs) that individually found statistically significant improvements in outcomes associated with the use of a systems approach. The only exception was for patient outcomes from studies that had concurrent controls in which the result showed an overall effect that slightly favoured the controls. However, the limited number of studies (4) included in this analysis limits its influence on the overall picture. In addition, we describe a number of factors, which may support success in the use of a systems approach. To our knowledge, this is the first systematic review that has endeavoured to conduct a comprehensive synthesis of the evidence-base for a systems approach to healthcare improvement.

This review adds to a growing number of systematic reviews apparently motivated by the desire to find evidence for what works in healthcare improvement. Similar reviews[19–23] of a systems approach in healthcare have focused on specific health issues such as patient safety, Human Factors and Ergonomics in healthcare, primary care, wellbeing of health workers and public health. Though these generally demonstrate value of a systems approach, they lack a rigorous and comprehensive assessment of the evidence-base for this. Other systematic reviews have been conducted on most of the major healthcare improvement methodologies including Lean[73], Six Sigma,[73,74] Plan-do-Study-Act (PDSA),[75] Statistical Process Control (SPC)[76] and Quality Improvement Collaboratives (QIC),[77] with mixed results. DelliFraine et al.[73] in their review of both the Lean and Six Sigma methodologies concluded that there is very weak evidence that either of the methods improves care. However, the review did not provide a meta-analysis of the studies identified and only focused on studies between 1999 and 2009, thus limiting its value. Taylor et al.[78] in their review of PDSA found poor compliance with the original principles of the methodology but did not aim to assess the impact of the method on outcomes. In the review of SPC, the authors found considerable benefits of using the approach to monitor and control health processes, though they acknowledge some limitations exist. Wells et al.[77] in their review of QICs reported significant improvements in process and patient outcomes. Their review reported outcome measures from included studies but stopped short of a full meta-analysis. Our findings are also consistent with the expectations of positive impact from the several publications that have called for a systems approach to tackling the challenges of modern health delivery systems.[10–16] There is, clearly, considerable interest in assessing the evidence-base of various improvement methodologies, however, existing systematic reviews have not been comprehensive enough and lack focus on patient and service outcomes.

Though the current review focuses on a systems approach to improvement, we believe this represents the most comprehensive systematic review and meta-analysis so far for evidencing the effectiveness of an improvement methodology. This is because we had no limits on date of publication, health setting, study type or participant types. We wanted the results to be relevant to a wide range of healthcare improvements contexts. However, one may object to our decision to combine very heterogenous studies as we have done because of the differences in clinical settings and outcomes being measured. We reasoned that the results of a combined study would be more useful to the healthcare community, practitioners and policy makers than an issue specific review. Moreover, several of those already exist, although not as rigorous. The inclusion of two RCTs in this review further strengthens the results. Though limited in number, both studies report statistically significant improvements in outcomes following the implementation of a systems approach.

Limitations

The major limitation of our study rests on the heterogeneity of the literature it seeks to synthesise, with wide variation in the settings, participants, comparators, follow-up durations, and study designs. We have sought to mitigate this using a clearly articulated definition of a systems approach, and a structured, rigorous, approach to synthesising the available evidence. The heterogeneity of meta-analysis results is to be expected, given the wide variation in participants, settings, interventions, comparators and outcomes. This exploratory meta-analysis can only indicate that systems approaches appear to be beneficial. This benefit must be interpreted and applied with care because the evidence mostly comes from before and after study designs, with inherent confounding factors of unknown magnitude and direction. There is also a significant risk of publication bias, and several included studies also reported both the potential of a Hawthorne effect and the existence of other interventions at the time of their study which may have contributed to their observed outcomes.

Implications for further research

The engineering sector is one that has excelled in the application of a systems approach[18]. The experience of the Systems Engineering community is that the value of a systems approach – in terms of quality of the resulting system, reduction in cost, delivery on time, customer satisfaction – corresponds to the extent to which a project or organisation commits to the approach.[79,80] This has implication for our findings in this review. It helps raise a number of questions that present opportunities for future research. For example, what are the different ways in which a systems approach is implemented in healthcare? Is there an association between the time and resource invested in a systems approach and the impact on patient and service outcomes? If so, what is the optimum level of investment?

Another opportunity for future research is a comparative review which assesses the impact of all improvement initiatives against those explicitly adopting a systems approach if more certainty of the value of the approach is desired. Given the volume of literature involved in such a comparative review, this would represent a significant undertaking. Studies are also needed that adopt better study designs such as RCTs or, if necessary, develop alternative ways of understanding and achieving sufficiently robust evidence for a systems approach to healthcare design and delivery. This is a point pertinent to all improvement efforts, where the traditional medical model of the randomised controlled trial is rarely appropriate, but the need to generate convincing evidence remains pressing.

Policy implications

We have argued from the start that there has been a growing recognition of the potential value of a systems approach to healthcare improvement over the past two decades. Most of this recognition has been at the policy level, involving the World Health Organisation (WHO),[81] the Institute of Medicine (IOM) in the USA,[3,4,12] the Department of Health in the UK[82,83] and more recently, through a joint initiative between the Royal Academy of Engineering (RAEng), Royal College of Physicians (RCP) and the Academy of Medical Sciences (AMS).[10] However, to support further research and increased practice of a systems approach in health and care, policy makers need to understand the evidence-base. Though several success stories and domain-specific reviews exist, a comprehensive review of the evidence across the healthcare literature has been lacking. Our review may, therefore, become invaluable to policy-makers who have found the argument for a systems approach conceptually appealing but also desire to see the evidence of what difference such an approach can make to patient and service outcomes. In addition, the references taken individually may serve as examples of real-world application of a systems approach to healthcare improvement.

Conclusions

In summary, we have argued that a systems approach to healthcare has been championed increasingly in the medical literature and in a variety of grey-literature reports and position documents. We provide the first attempt to, comprehensively, explore the evidence-base through a systematic review and meta-analysis. The results provide reasonable evidence that a systems approach to addressing health delivery challenges may lead to significant improvements in both patient and service outcomes.

Contributors

Conception and discussions: All authors; Database search: IK; Record scanning: AK, TB, JW, TD, GKK, YL; Full text review: AK, TB, JW, TD, GKK, YL, AG, JM, EO; Data extraction: AK, TB, JW, TD, GKK, YL, AG, JM, KK; Meta-analysis and interpretation: CM; Qualitative synthesis: AG, AK, NB; Quality assessment: KK, AG, AK, GKK, YL, TB, JW, JM, Manuscript writing: AK, TB, CM, AG, PJC, JD, EO; Final approval of manuscript: All authors

Funding

This research was supported by the National Institute for Health Research (NIHR) Global Health Research Group on Neurotrauma using UK aid from the UK Government and the Health Foundation funded THIS Institute (The Healthcare Improvement Studies Institute). The views expressed in this publication are those of the authors and not necessarily those of the NIHR, the Department of Health and Social Care, the Health Foundation or THIS Institute.

Competing interests

Dr Komashie reports grants from NIHR CLAHRC East of England, The Healthcare Improvement Studies (THIS) Institute and the NIHR Global Health Research Group on Neurotrauma, outside the submitted work. Dr Ward reports grants from National Institute for Health Research and the University of Cambridge, during the conduct of the study. Dr Bashford reports grants from NIHR Global Health Research Group on Neurotrauma, during the conduct of the study. Dr Dickerson reports grants from NIHR CLAHRC East of England, during the conduct of the study. All other authors declare no competing interests.

Ethical approval

Not required

Data sharing statement

No additional data available

Transparency statement

The manuscripts guarantor (AK) affirms that the manuscript is an honest, secure, accurate and transparent account of the study being reported; and that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Supplementary files

Supplementary file 1: Full search strategy – pdf.
Supplementary file 2: List of studies excluded after full text review with reasons – pdf
Supplementary file 3: Data extracted from included studies – pdf.

Acknowledgments

The authors acknowledge the help of the following bodies who provided financial support for members of the study team during the course of this work: the UK National Institute for Health Research Global Health Research Group on Neurotrauma (NIHR GHRGN), University of Cambridge, the UK National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care for the East of England (CLAHRC EoE), The Healthcare Improvement Studies (THIS) Institute. Our sincere thanks also go to Dr Nathan Crilly at the University of Cambridge Engineering Department, and Dr Guillaume Lame of CentralSupelec University in Paris for constructive review of versions of the manuscript and finally to Paul Driver of Anglia Ruskin University, Cambridge for help with improving the quality of our images.

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Figure captions

Figure 1: PRISMA systematic review process

Figure 2: The impact of a systems approach on patient outcomes – before and after studies

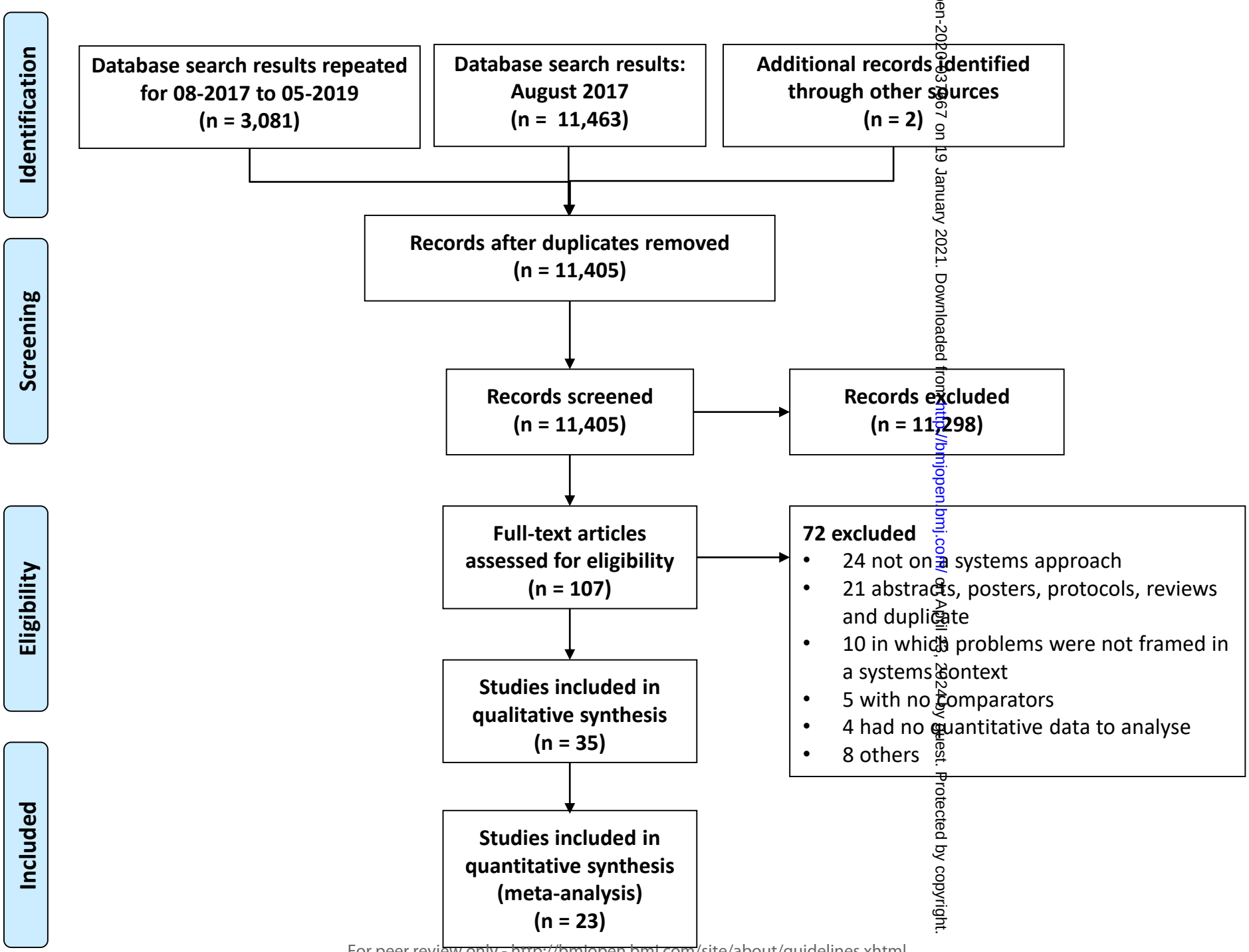
Figure 3: The impact of a systems approach on patient outcomes - studies with concurrent controls

Figure 4: The impact of a systems approach on service and resource use – before and after studies

Figure 5: The impact of a systems approach on service and resource use - before and after studies with continuous outcomes

Figure 6: The impact of a systems approach on service and resource use – studies with concurrent controls

Figure 7: Funnel plot using service outcome results



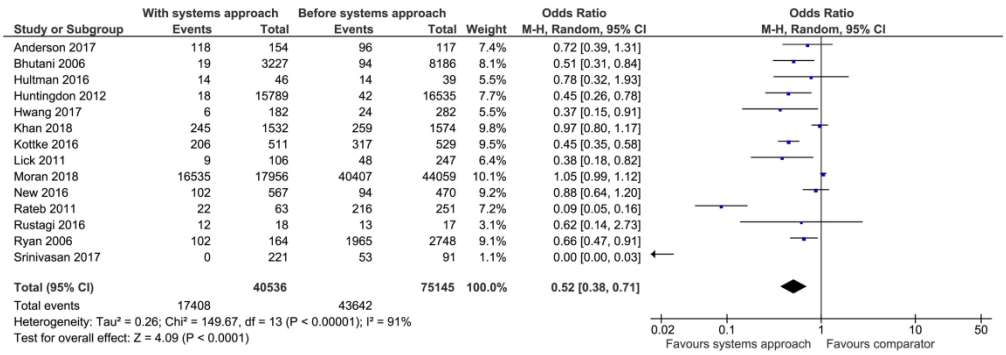


Figure 2: The impact of a systems approach on patient outcomes – before and after studies

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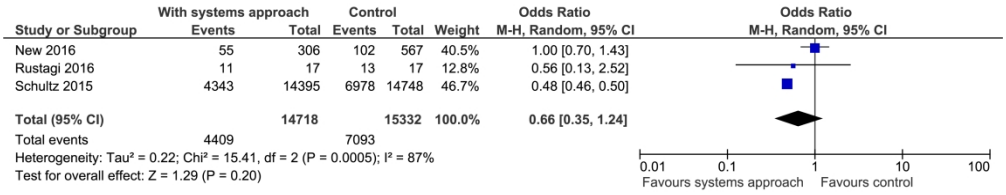

Figure 3: The impact of a systems approach on patient outcomes - studies with concurrent controls

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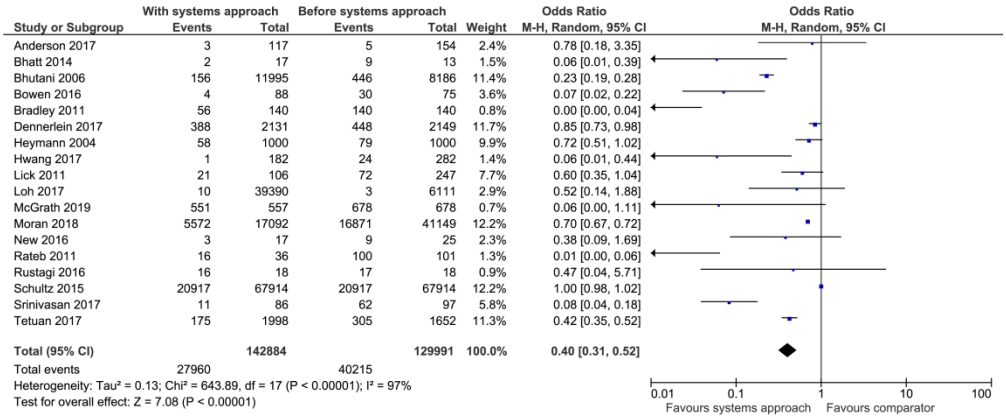

Figure 4: The impact of a systems approach on service and resource use – before and after studies

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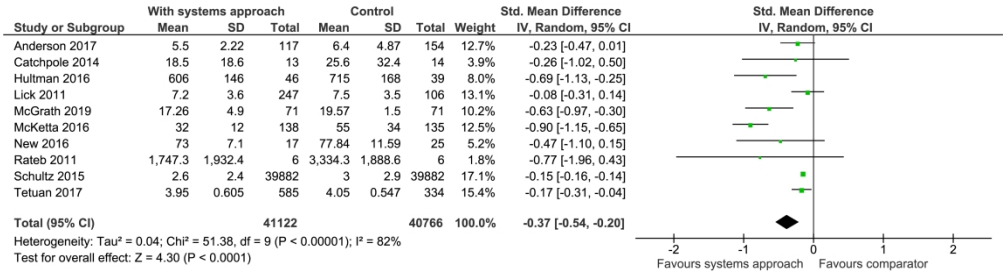

Figure 5: The impact of a systems approach on service and resource use - before and after studies with continuous outcomes

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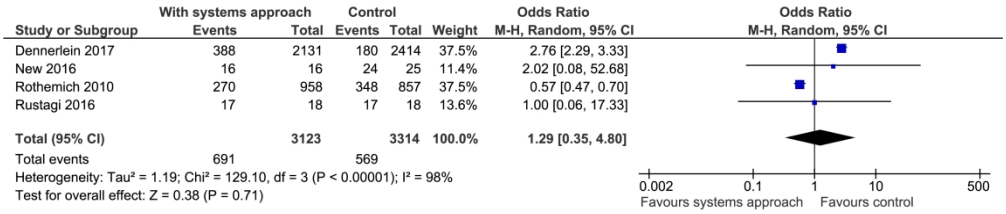

Figure 6: The impact of a systems approach on service and resource use – studies with concurrent controls

311x67mm (300 x 300 DPI)

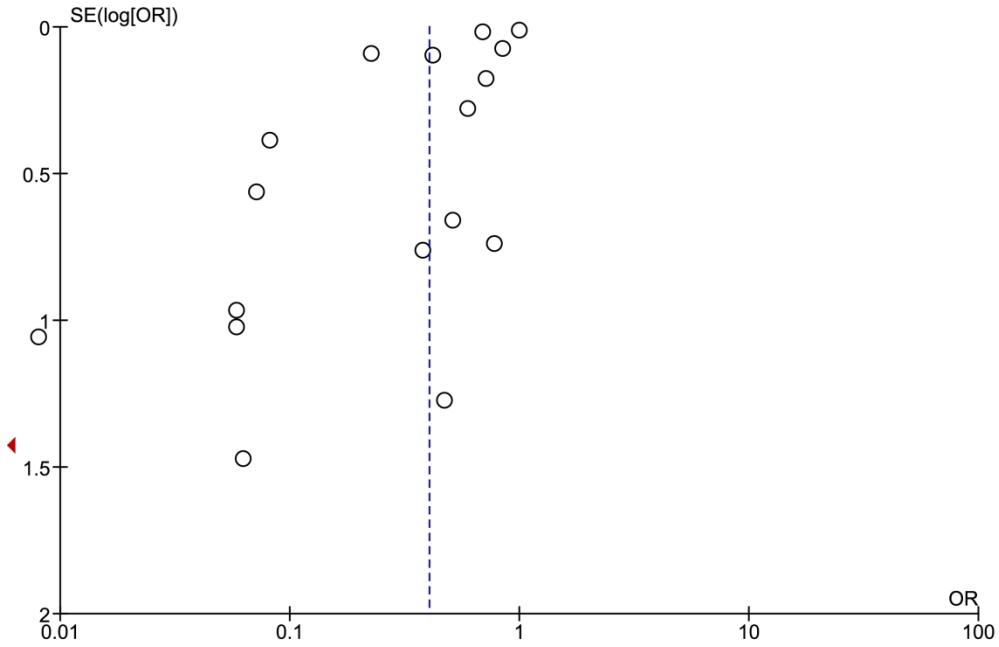

Figure 7: Funnel plot using service outcome results

211x141mm (300 x 300 DPI)

Full search strategy: Systems Approach to Healthcare Design

Database	No. of hits 10th August 2017	No. of hits since August 2017
Medline via OVID	1893	678
Embase via OVID	1351	347
HMIC via OVID	90	3
Health Business Elite via Ebsco	33	n/a
Web of Science	391	137
Scopus	7350	1795
PsycINFO via Ebsco	86	2
CINAHL via Ebsco	269	119
Total	11,463	3,081
Total Deduplicated	8,834	2,569

Searches run 28th May 2019

Medline

1. (((System or systems or systems-based) adj (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)).ti,ab. or exp Systems Analysis/ or exp systems theory/
2. (healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety adj3 patient*) or treatment outcome* or mortality or morbidity or (Health* adj3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))).ti,ab.
3. (design* or concept* or creat* or plan* or devis* or draft* or propos*).ti,ab.
4. (trial* or longitudinal* or (before adj3 after) or interrupted time series or control* or ((systematic* or literature*) adj review*) or meta-analys* or metaanalys* or (case adj (study* or control*))).mp.

5 1 and 2 and 3 and 4

6 ((201708* or 201709* or 201710* or 201711* or 201712* or 2018* or 2019*).dp. or (201708* or 201709* or 201710* or 201711* or 201712* or 2018* or 2019*).ez. or (201708* or 201709* or 201710* or 201711* or 201712* or 2018* or 2019*).ed.)

7 5 and 6

Embase

1. (((System or systems or systems-based) adj (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)).ti,ab. or exp *Systems Analysis/ or exp *systems theory/
2. (healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety adj3 patient*) or treatment outcome* or mortality or morbidity or (Health* adj3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))).ti,ab.

3. (design* or concept* or creat* or plan* or devis* or draft* or propos*).ti,ab.
4. (trial* or longitudinal* or (before adj3 after) or interrupted time series or control* or ((systematic* or literature*) adj review*) or meta-analys* or metaanalys* or (case adj (study* or control*))).mp.

5 1 and 2 and 3 and 4

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7 5 and 6

Web of Science

TS=((System* N1 approach*) or (system* N1 engineering) or (system* N1 science) or (system* N1 methodology*) or (system* N1 thinking) or (system* N1 dynamic*) or (system* N1 model*) or (system* N1 whole) or (system* N1 complex*) or (system* N1 ergonomics) or (system* N1 analys*) or (system* N1 theor*) or (discrete event simulation) or (sociotechnical) or (socio-technical))

AND

TS=(healthcare or (health care) or Medic* or (Health* service*) or care or nurs* or (safety N3 patient*) or (treatment outcome*) or mortality or morbidity or (Health* N3 quality) or (health* N3 safety) or (Health N3 efficien*) or (health N3 efficac*) or (health N3 performance*) or (health N3 outcome*) or (health N3 deliver*) or (health N3 experience))

AND

TS=(design* or concept* or creat* or plan* or devis* or draft* or propos*)

AND

TS=(trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review*) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*))

AND

#4 AND #3 AND #2 AND #1
Refined by: PUBLICATION YEARS: (2019 OR 2018 OR 2017)

CINAHL

#	Query	Results
	((EM 201708 or 201709 or 201710 or 201711 or 201712 or DT 2018 DT 2019 OR DT 2020)	

S7	S3 AND S4 AND S5 AND S6	269
S6	trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*)	836,166
S5	TI (design* or concept* or creat* or plan* or devis* or draft* or propos*) OR AB (design* or concept* or creat* or plan* or devis* or draft* or propos*)	485,564
S4	TI ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience)))) OR AB ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))))	1,054,215
S3	S1 OR S2	4,593
S2	TI (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)) OR AU (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical))	124
S1	(MH "Systems Theory+") OR (MH "Systems Analysis+")	4,493

PsycINFO

#	**Query**
	((EM 201708 or 201709 or 201710 or 201711 or 201712 or DT 2018 DT 2019 OR DT 2020)
S7	S3 AND S4 AND S5 AND S6
S6	trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*)
S5	TI (design* or concept* or creat* or plan* or devis* or draft* or propos*) OR AB (design* or concept* or creat* or plan* or devis* or draft* or propos*)

S4	TI ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience)))) OR AB ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))))
S3	S1 OR S2
S2	TI (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)) OR AU (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical))
S1	(DE "Systems Theory" OR DE "Systems Neuroscience") OR (DE "Systems Analysis")

HMIC – Health Management Information Consortium

1. (((System or systems or systems-based) adj (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)).ti,ab. or exp Systems Analysis/ or exp systems theory/
2. (healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety adj3 patient*) or treatment outcome* or mortality or morbidity or (Health* adj3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))).ti,ab.
3. (design* or concept* or creat* or plan* or devis* or draft* or propos*).ti,ab.
4. (trial* or longitudinal* or (before adj3 after) or interrupted time series or control* or ((systematic* or literature*) adj review*) or meta-analys* or metaanalys* or (case adj (study* or control*))).mp.

5 1 and 2 and 3 and 4

6 ((201708* or 201709* or 201710* or 201711* or 201712* or 2018* or 2019*).yr. or (201708* or 201709* or 201710* or 201711* or 201712* or 2018* or 2019*).dp.)

7 5 and 6

Health Business Elite this database is no longer available

#	Query
S7	S3 AND S4 AND S5 AND S6
S6	trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*)
S5	TI (design* or concept* or creat* or plan* or devis* or draft* or propos*) OR AB (design* or concept* or creat* or plan* or devis* or draft* or propos*)

S4	TI ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience)))) OR AB ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))))
S3	S1 OR S2
S2	TI (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)) OR AU (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical))
S1	(DE "SYSTEMS theory" OR DE "ASYMPTOTIC theory of system theory" OR DE "AUTOPOIESIS" OR DE "BIOLOGICAL systems" OR DE "CHAOS theory" OR DE "CONSTRUCTAL theory" OR DE "CYBERNETICS" OR DE "CYBERNETICS -- Social aspects" OR DE "DISCRETE systems" OR DE "EARTH system science" OR DE "LINEAR systems" OR DE "NONLINEAR systems" OR DE "OPEN systems theory" OR DE "OPERATIONS research" OR DE "SOCIAL dynamics" OR DE "SOCIAL systems" OR DE "SYNERGETICS" OR DE "SYSTEM analysis" OR DE "SYSTEMS engineering") OR (DE "SYSTEM analysis" OR DE "BEHAVIORAL systems analysis" OR DE "BOND graphs" OR DE "BUSINESS requirements analysis" OR DE "CONTROL theory (Mathematics)" OR DE "COUPLED problems (Complex systems)" OR DE "DECOMPOSITION method (Mathematics)" OR DE "DISCRETE-time systems" OR DE "DISTRIBUTED parameter systems" OR DE "ELECTRIC networks" OR DE "FLOW charts" OR DE "FLOWGRAPHS" OR DE "FUZZY systems" OR DE "HIPO technique" OR DE "INFORMATION modeling" OR DE "LARGE scale systems" OR DE "MAPS design technology" OR DE "MEMORYLESS systems" OR DE "SADT (System analysis)" OR DE "SAMPLE path analysis" OR DE "SMALL scale system" OR DE "SPATIAL systems" OR DE "STATE-space methods" OR DE "STOCHASTIC systems" OR DE "STRUCTURED techniques of electronic data processing" OR DE "SUBJECTIVE transfer function method" OR DE "SUPERPOSITION principle (Physics)" OR DE "SWITCHING theory" OR DE "SYSTEM identification" OR DE "SYSTEMS design" OR DE "TIME-domain analysis" OR DE "TRANSMISSION network calculations" OR DE "UNCERTAIN systems")

Scopus

(TITLE-ABS ((system* W/1 approach*) OR (system* W/1 engineering) OR (system* W/1 science) OR (system* W/1 methodology*) OR (system* W/1 thinking) OR (system* W/1 dynamic*) OR (system* W/1 model*) OR (system* W/1 whole) OR (system* W/1 complex*) OR (system* W/1 ergonomics) OR (system* W/1 analys*) OR (system* W/1 theor*) OR ("discrete event simulation") OR (sociotechnical) OR (socio-technical))) AND (TITLE-ABS (design* OR concept* OR creat* OR plan* OR devis* OR draft* OR propos*)) AND (TITLE-ABS (trial* OR longitudinal* OR (before W/3 after) OR ("interrupted Time series") OR control* OR ("systematic* review*") OR ("literature review*") OR meta-analys* OR metaanalys* OR ("case study*") OR ("case control*"))) AND (TITLE-ABS (healthcare OR ("health care") OR medic* OR ("health* service*") OR care OR nurs* OR (safety W/3 patient*) OR ("treatment outcome*") OR mortality OR morbidity OR (health* W/1 (quality OR safety OR efficien* OR efficac* OR performance* OR outcome* OR deliver* OR experience))))

Limit to 2017, 2018, 2019, 2020

Web appendix 1: List of studies excluded after full text review with reason for exclusion (n=72)

Summary

24 – Not a systems approach
21 – Abstracts, posters, protocols, reviews and duplicate
10 – Problem not framed in a systems context
5 – No comparator
4 – No quantitative data analysed
2 – Not been explicit about a systems approach
2 – Simulation results not applied in real-life
1 – Framed in a systems context but not evident in paper
1 – Not enough details on intervention
1 – Framework developed, not primary research
1 – About education in systems thinking

	Reference of excluded full text	Reason for exclusion
1	Dusek, J. A. *et al.* (2016) 'Patients Receiving Integrative Medicine Effectiveness Registry (PRIMIER) of the BraveNet practice-based research network: study protocol', *BMC Complementary and Alternative Medicine*, 16(1), p. 53. doi: 10.1186/s12906-016-1025-0.	Study protocol
2	Minkman, M., Ahaus, K. and Huijsman, R. (2007) 'Performance improvement based on integrated quality management models: what evidence do we have? A systematic literature review', *International Journal for Quality in Health Care*, 19(2), pp. 90–104. doi: 10.1093/intqhc/mzl071.	Literature review
3	Dhruva, A. *et al.* (2014) 'A Prospective Clinical Study of a Whole Systems Ayurvedic Intervention for Breast Cancer Survivorship', *The Journal of Alternative and Complementary Medicine*, 20(5), pp. A72–A72. doi: 10.1089/acm.2014.5189.abstract.	Abstract
4	Woods, A. (2008) 'Using lean/six sigma methodology to decrease error rate and cost of quality', *Transfusion,* Vol. 58 (supplement 2)	Poster
5	Dunbar, J. A.; O'Reilly, D. A. R.; Versace, V.; Sophy, S.; Janus, E. D (2017) Preventing progression to type 2 diabetes in women who have had gestational diabetes: Back to the drawing board?, European Association for the Study of Disease virtual meeting.	Poster
6	Boustani, M. A. (2017) Implementing the collaborative dementia care model in the real world.	Poster
7	Chandiramani, M. J.; … (2019) A multidisciplinary, multi-faceted approach to redesigning care pathways in the maternity assessment unit.	Abstract
8	P. W. Mirhosseini, C.;Hayes-Bautista, T. (2018) Depression screening: A "systems thinking" approach to address health disparities in ob/gyn practice	Abstract
9	S. J. C. Naidu, P.;Rosenthal, M.;Naik, S.;Patel, D.;Sawmynaden, V.;Cummings, S.;Jemmott, A.;Basi, M.;Hacker, K. (2019) An example of strategic collaborative working across a North Central London borough, over a 3-year period, to improve the care for people with diabetes and serious mental illness	Poster abstract
10	S. Y. Bakhai (2018) Implementation of integrated transition of care management in an academic, hospital-based safety-net primary care clinic	Presentation
11	Sherr, K. *et al.* (2014) 'Systems analysis and improvement to optimize pMTCT (SAIA): a cluster randomized trial', *Implementation science : IS*. England, 9, p. 55. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=24885976.	Protocol
12	Schnurr, P. P. *et al.* (2013) 'RESPECT-PTSD: re-engineering systems for the primary care treatment of PTSD, a randomized controlled trial', *Journal of General Internal Medicine*. United States, 28(1), pp. 32–40. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=22865017.	Not been explicit about a systems approach
13	Dietrich, A. J. *et al.* (2004) 'Re-engineering systems for the treatment of depression in primary care: cluster randomised controlled trial', *BMJ (Online)*.	Not been explicit about a systems approach
14	Muder, R. R. *et al.* (2008) 'Implementation of an industrial systems-engineering approach to reduce the incidence of methicillin-resistant Staphylococcus aureus infection', *Infection control and hospital epidemiology*. United States, 29(8), pp. 702–708. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med6&NEWS=N&AN=18624651.	Framed in a systems context but not evident in paper

15	Adesina, A. A. *et al.* (2017) 'Assessing the Value of System Theoretic Process Analysis in a Pharmacovigilance Process: An Example Using Signal Management', *Pharmaceutical Medicine*. Springer International Publishing, 31(4), pp. 267–278. doi: 10.1007/s40290-017-0195-5.	No comparator
16	Alimohammadzadeh, K. *et al.* (2017) 'Assessing common medical errors in a Children's hospital NICU using failure mode and effects analysis (FMEA)', *Trauma Monthly*, 22(5), pp. 1–6. doi: 10.5812/traumamon.15845.	No comparator
17	Arrington-Sanders, R. *et al.* (2018) 'A system-level approach to improve HIV screening in an urban pediatric primary care setting', *Pediatrics*, 142(5). doi: 10.1542/peds.2018-0506.	Not a systems approach
18	Bolton, K. A. *et al.* (2017) 'The outcomes of health-promoting communities: Being active eating well initiative- A community-based obesity prevention intervention in Victoria, Australia', *International Journal of Obesity*. Nature Publishing Group, 41(7), pp. 1080–1090. doi: 10.1038/ijo.2017.73.	Not a systems approach
19	Carrougher, G. J. *et al.* (2017) 'An Intervention Bundle to Facilitate Return to Work for Burn-Injured Workers: Report from a Burn Model System Investigation', *Journal of Burn Care and Research*, 38(1), pp. e70–e78. doi: 10.1097/BCR.0000000000000410.	Not a systems approach
20	Hilton, L. G. *et al.* (2019) 'Evaluation of an Integrative Post-Traumatic Stress Disorder Treatment Program', *Journal of Alternative and Complementary Medicine*, 25(S1), pp. S147–S152. doi: 10.1089/acm.2018.0424.	Not a systems approach
21	Hung, D. Y. *et al.* (2017) 'Scaling lean in primary care: Impacts on system performance', *American Journal of Managed Care*, 23(3), pp. 161–168.	Not enough details on intervention
22	Hussein, N. A. *et al.* (2017) 'Mitigating overcrowding in emergency departments using Six Sigma and simulation: A case study in Egypt', *Operations Research for Health Care*. Elsevier Ltd, 15, pp. 1–12. doi: 10.1016/j.orhc.2017.06.003.	Simulation results not applied in real-life
23	Kazemian, P. *et al.* (2017) 'Coordinating clinic and surgery appointments to meet access service levels for elective surgery', *Journal of Biomedical Informatics*. Elsevier Inc., 66, pp. 105–115. doi: 10.1016/j.jbi.2016.11.007.	Simulation results not applied in real-life
24	Lukes, T., Schjodt, K. and Struwe, L. (2019) 'Implementation of a nursing based order set: Improved antibiotic administration times for pediatric ED patients with therapy-induced neutropenia and fever', *Journal of Pediatric Nursing*. Elsevier Inc., 46, pp. 78–82. doi: 10.1016/j.pedn.2019.02.028.	Problem not framed in systems context
25	Martin, C. M. *et al.* (2019) 'Anticipatory care in potentially preventable hospitalizations: Making data sense of complex health journeys', *Frontiers in Public Health*, 6(JAN). doi: 10.3389/fpubh.2018.00376.	No quantitative data to analyse
26	Mutale, W. *et al.* (2017) 'Application of systems thinking: 12-month postintervention evaluation of a complex health system intervention in Zambia: the case of the BHOMA', *Journal of Evaluation in Clinical Practice*, 23(2), pp. 439–452. doi: 10.1111/jep.12354.	No quantitative data to analyse
27	Myers, M. K. *et al.* (2018) 'Using knowledge translation for quality improvement: An interprofessional education intervention to improve thromboprophylaxis among medical inpatients', *Journal of Multidisciplinary Healthcare*, 11, pp. 467–472. doi: 10.2147/JMDH.S171745.	Problem not framed in systems context though they say they performed a systems analysis
28	Redwood, R. *et al.* (2018) 'Reducing unnecessary culturing: A systems approach to evaluating urine culture ordering and collection practices among nurses in two acute care settings', *Antimicrobial Resistance and Infection Control*. Antimicrobial Resistance & Infection Control, 7(1), pp. 1–8. doi: 10.1186/s13756-017-0278-9.	No quantitative data to analyse
29	Steward, D., Glass, T. F. and Ferrand, Y. B. (2017) 'Simulation-Based Design of ED Operations with Care Streams to Optimize Care Delivery and Reduce Length of Stay in the Emergency Department', *Journal of Medical Systems*. Journal of Medical Systems, 41(10). doi: 10.1007/s10916-017-0804-6.	No baseline data
30	Adaba, G. B. and Kebebew, Y. (2018) 'Improving a health information system for real-time data entries: An action research project using socio-technical systems theory', *Informatics for Health and Social Care*. Taylor & Francis, 43(2), pp. 159–171. doi: 10.1080/17538157.2017.1290638.	No comparator
31	Akhter, L. S. *et al.* (2017) 'Improving Asthma Control through Asthma Action Plans: A Quality Improvement Project at a Midwest Community Clinic', *Journal of Community Health Nursing*. Taylor & Francis, 34(3), pp. 136–146. doi: 10.1080/07370016.2017.1340764.	Not a systems approach
32	Bal, A., Ceylan, C. and Taçoğlu, C. (2017) 'Using value stream mapping and discrete event simulation to improve efficiency of emergency departments', *International Journal of Healthcare Management*, 10(3), pp. 196–206. doi: 10.1080/20479700.2017.1304323.	No comparator in practice, just assume/simulate the future state
33	Losby, J. L. *et al.* (2017) 'Safer and more appropriate opioid prescribing: a large healthcare system's comprehensive approach', *Journal of Evaluation in Clinical Practice*, 23(6), pp. 1173–1179. doi: 10.1111/jep.12756.	Not a systems approach
34	Verbano, C., Crema, M. and Nicosia, F. (2017) 'Visual management system to improve care planning and controlling: the case of intensive care unit', *Production Planning and Control*. Taylor & Francis, 28(15), pp. 1212–1222. doi: 10.1080/09537287.2017.1358830.	Not a systems approach

35	Yusoff, N. S. M. *et al.* (2018) 'Discrete event simulation and data envelopment analysis models for selecting the best resource allocation alternative at an emergency department's green zone', *Sains Malaysiana*, 47(11), pp. 2917–2925. doi: 10.17576/jsm-2018-4711-35.	Not a systems approach, no comparator
36	Ammenwerth, E. *et al.* (2002) 'Systems analysis in healthcare: framework and example', *Methods of information in medicine*, 41, pp. 134–40.	Framework development not primary research
37	Boden, D. G. *et al.* (2016) 'Lowering levels of bed occupancy is associated with decreased inhospital mortality and improved performance on the 4-hour target in a UK District General Hospital', *Emergency Medicine Journal*, 33(2), pp. 85–90. doi: 10.1136/emermed-2014-204479.	Not framed in a systems context
38	Clark, C. *et al.* (2001) 'A Systematic Approach to Risk Managed Care Environment Improves', *Diabetes care*, 24(6), pp. 1079–1086. Available at: http://care.diabetesjournals.org/content/24/6/1079.full.pdf+html.	Not a systems approach
39	Gaupp, R., Körner, M. and Fabry, G. (2016) 'Effects of a case-based interactive e-learning course on knowledge and attitudes about patient safety: A quasi-experimental study with third-year medical students', *BMC Medical Education*. BMC Medical Education, 16(1), pp. 1–8. doi: 10.1186/s12909-016-0691-4.	About education in systems thinking
40	Gunn, J. *et al.* (2006) 'A systematic review of complex system interventions designed to increase recovery from depression in primary care', *BMC Health Services Research*, 6, pp. 1–11. doi: 10.1186/1472-6963-6-88.	Systematic review
41	Horbar, J. D. *et al.* (2004) 'Collaborative quality improvement to promote evidence based surfactant for preterm infants: A cluster randomised trial', *British Medical Journal*, 329(7473), pp. 1004–1007.	Not framed in a systems context
42	Press, A. I. N. (2005) 'A multifaceted collaborative quality improvement intervention significantly improves delivery of surfactant therapy for preterm infants', *Evidence-Based Healthcare and Public Health*, 9(3), pp. 219–220. doi: 10.1016/j.ehbc.2005.03.014.	Duplicate – same as Horbar et al (2004)
43	Jeon, Y. H. *et al.* (2012) 'Staff outcomes from the Caring for Aged Dementia Care REsident Study (CADRES): A cluster randomised trial', *International Journal of Nursing Studies*. Elsevier Ltd, 49(5), pp. 508–518. doi: 10.1016/j.ijnurstu.2011.10.020.	Not a systems approach
44	Jimmy, L. W. K. *et al.* (2009) 'Reduction in length of hospitalisation for microbial keratitis patients: A prospective study', *International Journal of Health Care Quality Assurance*, 22(7), pp. 701–708. doi: 10.1108/09526860910995038.	Problem not framed in a systems context
45	Kessels-Habraken, M. *et al.* (2010) 'Prospective risk analysis prior to retrospective incident reporting and analysis as a means to enhance incident reporting behaviour: A quasi-experimental field study', *Social Science and Medicine*. Elsevier Ltd, 70(9), pp. 1309–1316. doi: 10.1016/j.socscimed.2010.01.035.	No clear problem framed in a systems context
46	Lin, J. C. and Lee, T. T. (2016) 'Outcomes of medication administration information system for nurses', *Studies in Health Technology and Informatics*, 225(138), pp. 860–861. doi: 10.3233/978-1-61499-658-3-860.	Not a systems approach
47	Macfarlane, F. *et al.* (2013) 'Achieving and sustaining profound institutional change in healthcare: Case study using neo-institutional theory', *Social Science and Medicine*. Elsevier Ltd, 80, pp. 10–18. doi: 10.1016/j.socscimed.2013.01.005.	Not a systems approach, no quantitative results, does not aim to demonstrate effectiveness of SA
48	Mehta, A. D. *et al.* (2010) 'Poster 2: A System Redesign Approach to Improving Timeliness of New Outpatient PM&R Consults: Veterans Affairs Observational Analysis and System Redesign', *Pm&R*. Elsevier Inc., 2(9), pp. S9–S10. doi: 10.1016/j.pmrj.2010.07.033.	Poster
49	Miller, R. S. *et al.* (2010) 'Miller et al-2010-Systems initiatives reduce healthcare-associated infections.pdf', *The Journal of Trauma*, 68(1), pp. 23–31.	Not a systems approach
50	Mills, P. R., Weidmann, A. E. and Stewart, D. (2017) 'Hospital electronic prescribing system implementation impact on discharge information communication and prescribing errors: a before and after study', *European Journal of Clinical Pharmacology*. European Journal of Clinical Pharmacology, 73(10), pp. 1279–1286. doi: 10.1007/s00228-017-2274-7.	Not a systems approach
51	Moody-Thomas, S. *et al.* (2011) 'Awareness and implementation of the 2000 United States public health service tobacco dependence treatment guideline in a public hospital system', *Population Health Management*, 14(2), pp. 79–85. doi: 10.1089/pop.2010.0004.	Not a systems approach
52	Odetola, F. O. *et al.* (2016) 'An innovative framework to improve efficiency of interhospital transfer of children in respiratory failure', *Annals of the American Thoracic Society*, 13(5), pp. 671–677. doi: 10.1513/AnnalsATS.201507-401OC.	Not framed in a systems context
53	Palma, A. *et al.* (2013) 'Applying Systems Dynamics modeling to epidemiological research: an example of PSA screening', *American journal of epidemiology*, 175, pp. 1–145.	Abstract
54	Procter, S. *et al.* (2013) 'Success and failure in integrated models of nursing for long term conditions: Multiple case studies of whole systems', *International Journal of Nursing Studies*. Elsevier Ltd, 50(5), pp. 632–643. doi: 10.1016/j.ijnurstu.2012.10.007.	Not a systems approach, no comparator

55	Rahman, O. *et al.* (2010) 'Sustained reduction of ventilator associated pneumonia-use of an innovation system process in a tertiary care centre', *Critical care clinics*, 38(12).	Abstract
56	Raupach, T. *et al.* (2014) 'Structured smoking cessation training for health professionals on cardiology wards: A prospective study', *European Journal of Preventive Cardiology*, 21(7), pp. 915–922. doi: 10.1177/2047487312462803.	Not a systems approach
57	Sethi, R. *et al.* (2017) 'A systematic multidisciplinary initiative for reducing the risk of complications in adult scoliosis surgery', *Journal of Neurosurgery: Spine*, 26(6), pp. 744–750. doi: 10.3171/2016.11.SPINE16537.	Not a systems approach
58	Sethi, R. K. *et al.* (2014) 'The Seattle spine team approach to adult deformity surgery: A systems-based approach to perioperative care and subsequent reduction in perioperative complication rates', *Spine Deformity*. Elsevier Inc, 2(2), pp. 95–103. doi: 10.1016/j.jspd.2013.12.002.	New surgical protocol, not a systems approach
59	Singh, R. *et al.* (2012) 'IT-enabled systems engineering approach to monitoring and reducing ADEs', *American Journal of Managed Care*, 18(3), pp. 169–175.	Not framed in a systems context
60	Sobolev, B. G., Sanchez, V. and Vasilakis, C. (2011) 'Systematic review of the use of computer simulation modeling of patient flow in surgical care', *Journal of Medical Systems*, 35(1), pp. 1–16. doi: 10.1007/s10916-009-9336-z.	Systematic review
61	Solberg, L. I. *et al.* (1997) 'Delivering clinical preventive services is a systems problem', *Annals of Behavioral Medicine*, 19(3), pp. 271–278. doi: 10.1007/BF02892291.	Not a systems approach, no comparator
62	Spijker A, Verhey F, Graff M, et al. Systematic care for caregivers of people with dementia in the ambulatory mental health service: Designing a multicentre, cluster, randomized, controlled trial. *BMC Geriatr*. 2009;9(1):1-14. doi:10.1186/1471-2318-9-21	Protocol
63	Vats A, Goin KH, Villarreal MC, Yilmaz T, Fortenberry JD, Keskinocak P. The impact of a lean rounding process in a pediatric intensive care unit. *Crit Care Med*. 2012;40(2):608-617. doi:10.1097/CCM.0b013e318232e2fc	Not a systems approach
64	Vergales BD, Dwyer EJ, Wilson SM, et al. NASCAR pit-stop model improves delivery room and admission efficiency and outcomes for infants <27 weeks' gestation. *Resuscitation*. 2015;92:7-13. doi:10.1016/j.resuscitation.2015.03.022	Systematic but not a systems approach
65	Warner CJ, Walsh DB, Horvath AJ, et al. Lean principles optimize on-time vascular surgery operating room starts and decrease resident work hours. *J Vasc Surg*. 2013;58(5):1417-1422. doi:10.1016/j.jvs.2013.05.007	Not framed in a systems context, a narrowed application of lean
66	Carr, H. *et al.* (2019) 'A Systems-wide approach to prevention of in-hospital newborn falls', *MCN, The American Journal of Maternal/Child Nursing*, 44(2), pp. 100–107.	Not a systems approach
67	Carayon, P. *et al.* (2017) 'Medication Safety in Two Intensive Care Units of a Community Teaching Hospital After Electronic Health Record Implementation: Sociotechnical and Human Factors Engineering Considerations', *Journal of Patient Safety*, 00(00), pp. 1–11. doi: 10.1097/PTS.0000000000000358.	Not a systems approach
68	Scuffham, P. A. *et al.* (2017) 'Evaluation of the Gold Coast Integrated Care for patients with chronic disease or high risk of hospitalisation through a non-randomised controlled clinical trial: A pilot study protocol', *BMJ Open*, 7(6). doi: 10.1136/bmjopen-2017-016776.	Protocol
69	Cumbler, E. *et al.* (2012) 'Improving stroke alert response time: Applying quality improvement methodology to the inpatient neurologic emergency', *Journal of Hospital Medicine*, 7(2), pp. 137–141. doi: 10.1002/jhm.984.	Not set in a systems context
70	Firman, N. and Radrekusa, J. (2016) 'A systems approach to improving cancer screening outcomes through quality improvement strategies', *Journal of Gastroenterology and Hepatology (Australia)*. Netherlands: Blackwell Publishing, 31, pp. 54–55. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed18&NEWS=N&AN=612984556.	Protocol
71	Lipshutz, A. *et al.* (2015) 'The effect of a comprehensive unit-based safety program on systems thinking in adult ICU providers', 43(12), p. 2015.	Abstract
72	Chrysanthaki, T., Hendy, J. and Barlow (2013) 'Stimulating whole system redesign: Lessons from an organisational analysis of the whole system demonstrator programme', *Journal of health services research & policy*, 18, pp. 47–55.	No quantitative data to analyse

Web appendix 2: Data extraction tables

Table 1 - Characteristics of studies [population and intervention]

Study	Clinical area	Participants	Health setting	Type of Systems Approach	How implemented	Length of time applied	Training to staff	Perception of Systems Approach	How developed
Afsar-manesh et al., 2016[2]	Clinical Readmission rates	Staff (implementation) Patients (Data).	Whole Hospital-in General Medicine, General Surgery, Neurosurgery, Paediatrics, Orthopaedics	Comprehensive Lean methodology	System-wide leadership and promotion of improvement culture, patient-centeredness, process improvement and RCA in six clinical departments focused on reducing readmissions.	18 months	Created forum to share ideas and learn from colleagues and training in Lean principles.	System-wide with Lean principles	Used existing Lean principles
Bhatt et al., 2014[16]	Operating Rooms	Nursing staff, ORs	Academic Medical Centre	ACGME Core Competency of Systems-based Practice	Process redesign involving problem definition, process changes and a multidisciplinary TT team and through horizontal Integration.	17 days	Intervention trained. Surgical and TT team trained to implement the new system.	ACGME Systems-based Practice Team working and coordination.	Used existing ACGME Systems-Based Practice Pre intervention process analysed using structured approach.
Bhutani et al., 2006[15]	Maternity & Neonatal – new-born Jaundice	Well babies discharged as healthy, Patients' parents, Paediatricians, Paediatric nurses, Home care nurse agencies, Lactation support services,	Semi-private urban birthing hospital	Systems approach to Clinical Condition Management	Incremental chronological adoption of each element: a) 1990-1992 b) 1993-1995 c) 1996-1998 d) 1999-2000 Assessment of entire process 2001-2003 Incremental implementation of a systems approach that incorporated a hospital policy to (a) authorize nurses to obtain a bilirubin (total serum/ transcutaneous) measurement for clinical jaundice, (b) universal pre-discharge total serum bilirubin (at routine metabolic screening), (c) targeted follow-up, using the bilirubin nomogram (hour-specific, percentile-based total serum bilirubin/ transcutaneous bilirubin), and (d)	12 months	Parent education	An approach that relies on 1. Visual recognition 2. Measurement of bilirubin 3. Lactation and nutrition support 4. parent education including follow-up and is considered Systematic Multifactorial An 'approach that does not deteriorate over time and has institutional memory	Incremental changes to managing treatment of jaundice in new-borns Developed through literature review Systematisation of approach (algorithm generation)

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					an organized institutional systems-based management of newborn jaundice				
Bradley et al., 2011[14]	Primary care	Primary Healthcare Units (PHCU) – Patients	Primary care in Rural Ethiopia	The Ethiopian Millennium Rural Initiative "By systems-based, we mean healthcare improvement efforts that target all patients rather than those with specific diseases and that can be standardized and replicated across the country over time."	Through the elements of EMRI model: (i) improving the infrastructure of health centres (i.e. water, electricity, physical infrastructure and equipment), (ii) improvement in the supply chain (e.g. transport of specimens and results follow-up), (iii) human resource capacity building through health worker training and on-site clinical mentoring, (iv) developing a system to improve referrals between health posts and health centres and (v) community education and mobilization	18 months	Approach involved community education and mobilization Health worker training and on-site clinical mentoring.	A focus on health infrastructure, supply chain, human resource, between centre referral systems and community education and mobilization	Part of national health sector development efforts. No specific details As part of the Ethiopian Millennium Rural Initiative
Catchpole et al., 2014[13]	Trauma care	Trauma Patients	Nonprofit, Academic tertiary care medical centre	Although the paper applies Human Factors Engineering, there is no clear emphasis on such an application as being part of systems engineering or systems approach. Yet, they unintentionally referred SEIPS and PDSA (iterative)	A multidisciplinary team was brought together for one and a half days to define problems and identify solutions. The main problem areas were identified, and a range of potential solutions to each were generated. Then, a short list was generated based on practical considerations or the projected time needed for implementation. This short list was framed within the components of the SEIPS model. After the meeting, members of the ED and trauma teams were invited to discuss the short list and be involved in the studies. As implementation moved forward, they used small, iterative PDSA to develop each intervention to a level where it was practical and deliverable.	5 months	None	Unintentional. SEIPS just to frame potential solutions, to ensure coverage of task, team, environment and technology.	Used existing SEIPS human factors model
Dennerlein et al., 2017[17]	Patient Handling and	Direct Patient Care Workers	Hospital-wide -at 2 hospitals	A broad stakeholder engagement from senior level down,	High-level buy-in with a multidisciplinary oversight committee chaired by the Associate	12 months	Yes, Programme training was provided to all	System-wide and multi stakeholder and multi processes	Developed by a committee to include key component

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	mobilisation			new lifting equipment across hospital, new processes and group training and one-to-one coaching and mentoring for staff	Chief Nurse of Quality and a Collaborative Coordination Committee including Associate Chief, Occupational health ergonomists and nurse business officer The hospital expanded its investment in ceiling lifts, slings, sit-to stand devices and etc. The coordinating committee developed processes ensuring that all equipment was in working order and portable devices were stored on the units and readily available for use.		nurses, nurse directors and patient care assistants. An external consultant provided an online introductory module, followed by group training and one-on-one coaching and mentoring at the bedside.	Hospital-wide, and involvement of different stakeholders and multi components	identified by previous systematic reviews, including an organisational policy aimed at reducing injuries, investment in equipment broad-based training within the context of providing tools and risk assessment
Hathout et al., 2013[19]	Sleep disorders	Healthcare staff	Province-wide, Manitoba, Canada	Stakeholder engagement, problem exploration, process mapping, exploration of systems drivers and value and objectives of services	A project steering committee setup decided what is to be done. Consultations took place with stakeholders, staff, patients, administrators and managers. A multi-disciplinary team was convened to improve the system to meet the population's needs. They articulated a vision, conducted a demand analysis, and then described the current state of the system. Using the demand analysis and their understanding of the current state they defined the desired state and worked through the process changes requirements to bridge the gap from the current state to the desired state.	18 months	Wide consultations, but PSG training was recommended as a result of the study	Stakeholder involvement, deep exploration of problem and system understanding (system drivers), its problems and stakeholders' needs.	A multidisciplinary team was convened to improve the system to meet the population's needs.
Heymann et al., 2004[18]	Antibiotic overprescribing	Healthcare professionals-Staff	Maccabi Healthcare services, a Health Maintenance Organisation (HMO) serving 1.5M patients	Previously developed Systematic Inventive Thinking (SIT). Bases on "Creativity as an exact Science" by Genrich Altschuler	A multidisciplinary group was formed to work through the SIT steps – problem reformulation, general search strategy selection and application of idea-generation techniques. Results launched through national media campaign.	14 months	Not reported	Multiple stakeholder engagement, deep problem exploration, with focus on creative solutions. Unintentional, it has the elements of systems thinking, but the paper uses a systematic approach to solve complex problems	Based on previous work

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Huntington et al., 2012[22]	Maternal Health	Women's health teams	Health systems reform in a province in the Philippines involving two tertiary hospitals , 20 first level referral health facilities. Twelve rural health units. One barangay (neighbourhood or village) health station	National initiative - National Safe Motherhood Programme. Seems influenced by WHO health systems strengthening principles	Implemented through national Department of Health initiatives Speed of implementation seems to have been the interventional factor. Fast in one province; normal in five provinces.	4 years	Intervention province reported that 74% of their referral providers had completed competency-based clinical training programme. No information on clinical training was available for the comparison provinces.	Holistic understanding of a system's building blocks, identifying where a system succeeds, where it breaks down and what kinds of integrated approaches will strengthen the overall system.	No details reported. Appears influenced by WHO health systems strengthening principles.
Hwang et al., 2017[6]	Cardiac care	Patients	Multiple institutions in the chain of survival of cardiac arrest patients – community to hospital	System-wide CPR programme for OHCA patients developed by lead Hospital.	Started by identification of weak points in chain of survivor, CPR education sessions, improved records captured by EMS new protocol for ACLS at ED formulated by a multidisciplinary team.	12 months	CPR education for public at schools and workplaces.	"System-wide". Lots of emphasis on scope – who is involved – rather than how. Analysis of delivery system weaknesses in CA survival and multi interventions approach to address those weaknesses.	Developed in-house. No reference to any previous work.
Kottke et al., 2016[21]	Primary care - Coronary Heart Disease	Patients	Private, five-clinic primary care practice	Complex Adaptive Systems principles	Each clinic developed own system using systems' personnel including RN, Care Manager, IT staff and Clinic Assistant Care Coordinators. Activities related to patient care delivery, provider staff, staff education, training and tool development and information technology Through Team Based working.	6 months	Clinical service staff trained for use previsit planning tool. Patient education materials. Including clinical based skills and CQI.	"1. health service delivery systems are complex adaptive systems, not mechanical systems, 2. Adoption of any system of care requires adaptation and reinvention and 3. The long-term survival of any system of care requires that a new process, at a minimum, does not threaten the viability of the overall system."	Using existing CAS theory to design interventions.

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Lick et al., 2011[8]	Cardiac Arrest	Patients	Community-based centres of excellence	"Take heart America programme". Community-based initiative involving 1. Widespread Cardiopulmonary resuscitation 2. Retraining of all emergency medical service personnel 3. Additional deployment of automated external defibrillators and 4. Protocol for transport to and treatment by cardia arrest centres.	Site coordinator appointed to work in lead hospitals in each of two counties. Coordinators established collaborations and implemented THA with city administrators, police and fire departments, school system administrators, survivors and survivor network organisations, ALS support team members, hospital administration and key clinicians in each Cardiac Arrest Centre (CAC).	6 months	Extensive Community CPR training, Public awareness, dispatcher instructed CPR, Advanced Life Support training for staff.	Emphasis appears to be on the wide coverage of the programme – community-side and multi-agency. Take Heart America (THA) model of improving care.	Developed by implementing all the high level 2005 American Heart Association (AHA) CPR and Emergency Cardiovascular Care Guidelines in a community-wide systems approach based on treatment models for other complex diseases such as HIV
Loh et al., 2017[5]	Cataract Surgery	Patients	National tertiary specialist hospital	SEIPS Model/ PDSA	SEIPS used as framework for classification of problem, PDSA approach to improvement 1. Retrospective study 2. Qualitative descriptions of incidents. 3. Applied SEIPS as a reference framework.	6 months	Briefing of staff on data collection and weekly reminders	SEIPS framework	Existing approach Standard SEIPS model tailored to the case in question.
McKetta et al., 2016[7]	Paediatric Cardiac procedures	Physicians Nurses Technicians Improvement specialists	The Cardiac Centre at a Children's Hospital	A Discrete Event Simulation together with traditional QI involving a multidisciplinary team using a four-step framework – Define, Diagnose, Test and Implement, and Sustain. Including PDSA	Implementation led by a multidisciplinary team of physicians, nurse practitioners, nurses, technician and improvement support using an in-house framework- Define, Diagnose, Test and Implement, and Sustain. Tests were evaluated using PDSA cycles.	4 months	Not reported Daily debrief to sustain performance	Discrete Event Simulation (DES) as a tool for analysing complex systems Change management in complex systems. DES combined with QI a model for addressing this. Aim to maintain throughput during resource restriction (closed procedure suite).	A previously developed DES model was used and a four-step improvement framework developed in-house.
New et al., 2016[11]	Trauma & Orthopaedics	Theatre staff	The Orthopaedic trauma theatre of a UK hospital Trust	A two-step intervention – one-day Lean training followed by 6 months coaching. Training covered	The multidisciplinary team decided on improvement project after training and carried it out with support from experts.	6 months	A whole day training for a multidisciplinary staff team and practical training for project team during	A comprehensive Lean approach.	Existing method - Lean

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				Lean principles – Muda, Poka-Yoke, Genchi Genbutsu, Kaizen, flow, JIT, respect and teamwork, process mapping, PDCA cycles and a philosophy of continuous participative experimental improvement. Then a six-month improvement project.			the improvement process Training in lean theory and methods with subsequent support and encouragement – one day training with light-touch coaching for six months (nurses, surgeons, anaesthetists and administrators)		
Rateb et al., 2011[10]	Health Insurance Organisation (HIO), pre-employment medical fitness check-up	Doctors, nurses, administrative staff, and customers	Egypt HIO / community, Medical fitness testing.	Business Process Re-engineering focusing on Structure, Process and Outcome. Systems approach appears to mean everything from building renovation to customer and staff satisfaction	Conducted brainstorming sessions involving stakeholders, decision makers, service providers and beneficiaries. Randomly selected six centres to take part in re-engineering phase which was implemented in three stages.	Can't Tell	New services, processes and standards introduced. IT training for staff	The entirety of Structure, Process and Outcome of care Business Process Re-engineering (BPR)	Approach developed by team using BPR concepts and Donabedian's model
Rothemich et al., 2010[12]	US Family Practice / Public Health: smoking cessation	Adult smokers and Family physicians, general internists, nurse practitioners, physician assistants.	16 primary care practices	Called QuitLink Intervention. Limited details provided. Described as using paper-based, systems approach to identify smokers, provide advice to quit, and assess willingness to quit. Includes supporting willing smokers too access quitlines and communicate feedback from quitline to clinicians	Selected practices were randomised into a control group and an intervention group. A nurse liaison provided training to all rooming staff at intervention practices on QuitLink implementation procedures. 1. Practice recruitment via researchers. 2. 2-month 'wash-in period' to incorporate methodology, install resources (quitline stamp and fax referral), train staff, obtain baseline data, and define analytic strata	1 months	Training for staff, office manager and some clinicians. Nurses and medical assistants trained in the QuitLink implementation, given a customised 'stamp', protocol process explained.	Ensuring communication from clinician to quitline and feedback from quitline to clinicians or a systematised population-health intervention with multiple points of action.	Self-developed: Synthesised from an evidence base around smoking cessation services – the approach used designed to address most of the perceived deficiencies in previous attempts.

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					3. Comparison period involving ongoing outcome measurement				
Rustagi et al., 2016[1]	HIV AIDS	Healthcare staff and Patients	Mother-to-child HIV transmission prevention services in three countries in Africa – Cote d'Ivoire, Kenya and Mozambique	The Systems Analysis and Improvement Approach (SAIA) – a 5-step, iterative package of systems analysis and improvement tools developed using multiple systems engineering techniques including continuous quality improvement.	4-day workshops were held at each intervention facility to introduce and prepare staff for the intervention, follow-up visits were conducted weekly for 4 weeks, biweekly for 8 weeks after and then monthly visits thereafter or as needed by staff.	9 months	Training and support regular support provided for staff	Approach targets wider system from district level to local processes and action. Tools in SAIA include Cascade analysis tool – excel spreadsheet for quantitative analysis of patient flows, Value Stream Mapping (VSM) and PDSA	Self-developed based on multiple existing systems engineering tools.
Ryan et al., 2006[9]	Alcohol detoxification	Service users	Manchester Alcohol Service (MAS) In-patient detoxification service	A whole systems approach to alcohol services – A collaborative working between multiple organisations	Implementation of approach occurred with new contracts issued to each of the providers: in-patient and home detoxification, community treatment, day care and access into rehabilitation services and other wrap-around services	Can't Tell	No	Collaborative working between organisations that individually addressed different parts of the needed service.	Previously developed and implemented MAS system. Current study only provides retrospective evaluation.
Shultz et al., 2015[4]	Vaccine administration	Physicians and staff	5 Family Medicine Clinics and 4 Internal Medicine Clinics (as control)	Sequential and linked PDSA/Adjust cycles. A consensus-based framework that addresses the process of care.	Using collaborative working, five community-based family medicine clinics at the university of Michigan modified a point-of-care decision-support system for to improve administration and documentation Tetanus, diphtheria and acellular pertussis vaccines for patients.	Two years	Clinicians, nurses, medical assistants and support staff were trained to use the newly developed Automated Clinical Reminder (ACR) system.	A focus on Structure (physical environment and context of care), process (actions and procedures associated with the delivery and documentation of care) taking the needs of people into account.	An existing Automated Clinical Reminder (ACR) system was modified through consultations with clinicians, nurses, medical assistants, and support staff from each clinic.
Tetuan et al., 2017[3]	Medication administration	Nurses	Integrated health care systems comprising primary and speciality clinics, and a 568-bed acute care hospital.	Systems Thinking Education Programme (STEP)	Medication huddles and monthly Organisation-wide education for 1yr. 1. Staff training (over 12 months) on systems thinking 2. Medication huddles 3. Observation audits of the medication administration process	12 months	Monthly trainings for 1yr Training of trainers for medication huddles, and direct subsequent training of other staff.	System-wide: Multifaceted intervention based around a definition of systems thinking as "the ability to recognise, understand, and synthesis the interactions and interdependencies in a set of components designed for a specific purpose".	Literature review of systems thinking, error detection, and safety culture.

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Allaudeen et al.	Emergency care	ED patients and staff	University-affiliated department of veterans affairs medical centre	Lean-based multi-disciplinary initiative and PDSA	Delivered a rapid process improvement workshop to evaluate current processes, identified root causes of delays and developed counter-measures and standard work. The standard work was put into practice and monitored, feedback on success was obtained. Barriers to success were identified, and PDSA cycles were followed in response. Daily management systems to re-inforce, evaluate and refine standard work were also developed.	3 years 1yr pre-intervention period; 3yrs post-intervention period (this appears to include 1yr implementation period)	Not specified	Lean-based and multi-disciplinary	Standard approach – Lean
Anderson et al.	Geriatric hip fracture	Geriatrics patients and staff including a clinical leadership team, clinical participants and senior management.	The University of Colorado hospital academic medical centre	"Step-wise framework for implementing a comprehensive geriatrics hip fracture program" involving twelve steps	A series of 12 steps, comprising elements such as: assembling a team, conducting a gap analysis, establishing reporting measures, designing and implementing interventions, and evaluating outcomes.	17 months Pre-intervention (1/1/2012 – 28/10/2014), Post intervention (29/10/2014 – 31/03/2016) Implementation period (03/2014 – 10/2014	Can't tell	Step-wise and comprehensive involving a wide range of stakeholders and taking account of local context.	Self-developed but seems to be informed by Kotter: Kotter JP. Leading change: Why transformation efforts fail. Harv Bus Rev 2007 Jan:1-10.
Bell et al.	Antenatal care (smoking cessation among pregnant women)	Pregnant women	Eight acute NHS hospital trusts and 12 local authority areas in North East England	"BabyClear" – a complex intervention comprising a package of measures designed to support implementation of national guidance	Training for staff in participating agencies in skills, supporting materials, and implementation of referral pathway.	4 months Implementation between 11/2012 and 07/2013 Pre and post-intervention	Training provided for staff in participating agencies in CO monitoring, communication skills, skills training	Complex intervention, change in overall system of care - Multi-agency referral pathway with follow-up protocol	Developed by Tobacco Control Collaborating Centre, part of a larger Improving Performance in Practice programme.
Bowen et al.	Stroke care	Stroke patients	Grady Memorial Hospital - Single centre, hospital, stroke centre	Multi-stakeholder process mapping to inform problem identification involving value stream mapping	Workflow process map was developed over a period of two months involving paging dispatcher, university call centre and emergency medical services manager. Included working with	32 days Pre-intervention (April 20 – May 6 2014),	Can't tell	Multiple stakeholder involvement in mapping processes to inform improvement - value stream mapping (Lean)	Standard method – process mapping

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					equipment vendor to test and confirm problem identified and supply appropriate equipment.	Intervention (May – Sept. 2014), Post-intervention (Sept. 17 – October 19 2014)			
Cochran et al.	Emergency room	Patients, nurses and a team of ER and system engineering specialists	Franciscan Health Indianapolis – a general medical and surgical centre	Collective System Design (CSD) methodology involving PDCA – a systems engineering methodology, which recognises systems as the amalgamation of four key elements: Work/Actions, Structure, Thinking and Tone.	Senior leadership and ER team worked to identify the needs of internal and external customers, identified system boundaries, developed a CSD map and applied PDCA to design the relationships on the map for the purpose of implementation. Electronic logs of the medical centre was used to establish baseline.	8 months Pre-intervention (8 months), Post-intervention (8 months)	Can't tell	Recognition of a system as an amalgamation of four key elements that are always present and completely interrelated - work/actions, structure, thinking and tone or culture. Also defining stakeholders and the system boundary, understanding the needs of stakeholders, and determining the functional requirements to develop solutions.	Can't tell
DeFlitch et al.	Emergency departmen t	Patients and staff	A suburban, tertiary care, academic ED, with paediatric and adult level 1 trauma.	"Engineering techniques" including defining a study team, process mapping, Discrete Event Simulation modelling and detailed design considerations leading to the Physician directed Queuing (PDQ) model.	A study team was setup to carry out project. The team examined the operational data from our ED information system (EDIS), charted patient arrival patterns, conducted interviews of staff, observed staff with patients, and mapped the ED processes of care. Proposed model was tested in a simulation and piloted before implementation.	3 years Pre-intervention (July 2005 – June 2006), Post-intervention (July 2009 – June 2010) Intervention (July 2006 – June 2009)	Student educational training	Engineering techniques that involve process mapping and simulation modelling and visualization of the operation of the system.	Use of existing tools - process mapping and simulation plus self-developed processes.
Gupta et al.	Chemother apy	Healthcare staff and patients	Parkland health and hospital system – a large public hospital in the USA	A multi-disciplinary team delivering PDSA including process mapping.	A multi-disciplinary team involving nurses, pharmacists, physicians, QI training programme coach, QI experts, IT analysts, unit secretary and patient representatives conducted assessment of existing waiting times, identified factors and conducted two cycles of PDSA.	6 months Pre-intervention (Jan. – Feb. 2017) Intervention (PDSA 1, Aug. – Sept. 2017;	Can't tell	Focused on developing a preadmission process that streamlined patient evaluation on admission and improved communication.	Existing method – PDSA and process mapping.

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						PDSA 2, Sept. – Oct. 2017) Post-intervention period not defined.			
Hultman et al.	Breast reconstruction	Healthcare staff and patients	Academic medical centre of the University of North Carolina Hospitals	Lean-Six Sigma – using standard DMAIC model	A multi-disciplinary project team involving microsurgeons, anaesthesiologists, circulating nurses, surgical assistants liaising with other stakeholders.	24 months Pre-intervention (24 months), Intervention (10 months), Post-intervention (24 months)	Some team members were trained in six sigma with blue, green and yellow belts.	Six Sigma with multiple stakeholders	Existing method – Six sigma
Khan et al.	Paediatric inpatient unit	Patients, parents or caregivers, nurses, medical students and residents	Paediatric inpatient units in seven North American hospitals in USA and Canada	Co-production of intervention to standardise the structure of healthcare provider-family communication on family centred rounds.	A team of parents, nurses and physicians including health service researchers, medical educators, hospitalists, communication experts and health literacy experts coproduced the intervention to standardize healthcare provider-family communication on ward rounds ("family centered rounds"), which included structured, high reliability communication on bedside rounds emphasizing health literacy, family engagement, and bidirectional communication.	3 months - Pre-intervention (3 months), Intervention (9 months), Post - intervention (3 months) Entire project lasted 25 months (December 2014 – January 2017)	A rounds training and learning programme for interprofessional team members.	Health service user centered (patients and families involved in production of the intervention). Intervention addressed multiple elements of the system i.e. targeted key stakeholders with education but also implemented process changes, such as the mid-shift nurse-physician huddles. Intervention assessed across multiple domains, including reductions in medical errors and family experience.	Self-developed - A team of parents, nurses, and physicians, including health services researchers, medical educators, hospitalists, communication experts, and health literacy experts, coproduced the intervention—the Patient and Family Centered I-PASS
McGrath et al.	Postoperative surgical care& General medical inpatient care	Patients and staff including Nurses, Nurse Assistants, Occupational therapists, Physical therapists, Physicians	US Academic Health Centre	System-level design and analysis involving system design and validation, installation and education, operation and performance measurement	System design and validation phase was used to set goals for improvement based on organisational data and review of existing systems. Following elicitation of desired improvements and compilation of feature list, workshops were held with technical and clinical stakeholders to develop integration, installation,	5 months - Pre-intervention (5 months), 2 months of intervention Post-intervention (5 months)	Education materials were created and delivered to staff to assist in understanding purpose, goals and to orient staff to new system, operation, workflows, and	Systematic technical and workflow design, implementation and performance measurement phases. Views the systems element as a preparation phase of exploration, piloting, and validation. Then moves into discrete implementation and measurement phases	Not clear. No specific tools or approaches mentioned, and no clear grounding in systems literature.

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					workflow and safety specifications and processes for selected system.		medical record processes.	which seem separate to the systems element.	
Moran et al.	Major trauma	Population of England and wales- All hospitals in England and Wales (primary analysis done on 35 'constant submitter' units)	UK NHS in England and North Wales	Trauma systems – Systematic trauma care on a national basis.	NHS reorganisation creating a series of Regional Networks designated as Major Trauma Centres, with funding through a 'Best Practice Tariff' only available to MTCs over and above the normal funding for such patients. Data collected longitudinally through the Trauma Audit and Research Network (TARN).	4 years - Pre-intervention (Apr. 1st 2008 – Mar. 31st 2009) Intervention (2009/10 – 2011/12) Post-intervention (2013/14-2016/17)	Can't tell	Rationalised provision of trauma care through coordinated networks with an MTC hub.	Comparison with experience in the US. No clear reference to systems thinking literature.
Srinivasan et al.	Paediatric inpatients	1 -23 month old Babies and parents and paediatric hospitalists, paediatric emergency medicine physicians, nurses, residents, interns, and nurse practitioners.	Emergency department and inpatient unit of a 280-bed tertiary care, free-standing children's hospital	Driver Diagram plus three cycles of PDSA involving stakeholder surveys focusing on changing clinician behaviour through both education, reinforcement and encouragement.	A stakeholder survey was conducted and a multi-disciplinary team was set up. Stakeholder responses were turned into a driver diagram and projects for 3 PDSA cycles with a 3 week period at the end of each cycle and a wide engagement of stakeholder with results of each cycle.	3 weeks - Pre-intervention (Jan. 2015 – Apr. 2015), Intervention (Jan. 2016 – Apr. 2016) Post-intervention period unclear appears to be 3 weeks.	Face to face by study team to clinical providers during routine meetings, email communication to those not attending meetings, posters in clinical areas, pocket cards for clinicians, parental information sheets, walk-throughs 3 times per week to trouble shoot.	Systems changes seem conceptually confined to process changes (NG feeding tube order set) and physical changes (stocking of ED with appropriate supplies). However, the driver diagram denotes different interventions having an impact on multiple possible drivers, more consistent with a systems thinking approach.	Existing method – PDSA and Driver Diagram. Explicit reference to PDSA cycles but not to systems thinking/approaches
Chandrasekar et al.	Acute Kidney Injury	All medical inpatients at a single UK hospital	A university hospital in the UK	'QI Methodology' including driver diagrams, pareto charts and statistical process analysis Also includes a range of interventions involving risk assessment tools, early identification using automated alerts, development	A multi-disciplinary project team was given remote QI training and met at a weekly huddle. Preparation strategies included mapping stakeholders, patient journeys and current processes. 3 years of data were analysed, a driver diagram and standard QI charter were developed to guide project. Also included: - staff education and awareness program,	34 months - Pre-intervention (Jan. 2011-oct. 2013), Post-intervention (Oct. 2013 – Jul. 2016) Entire project lasted 5 years	Remote training in QI for the team plus weekly huddles. Also staff engagement package, posters, seminars for key staff groups, formal and informal awareness events in the hospital	The project recognises multiple elements of the system as contributing to the problem (as evidenced by their driver diagram). The intervention attempted to address multiple elements within the system: staff knowledge, electronic patient health record prompts, new	The project was triggered following a mortality analysis at the trust and joint collaboration with Institute of Healthcare Improvement in Boston, USA. The team went through remote training in QI, sought to influence

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				of an intervention bundle, formation of an outreach support team staff engagement and patient and family empowerment.	- development of a patient specific electronic alert to prompt diagnosis - implementation of a memorable AKI care bundle (ABCDE-IT), - creation of a new dedicated AKI outreach team - patient and family empowerment			packages/care processes for patients with AKI Stakeholder mapping, mapping of patient journeys and identification of key care processes.	business intelligence reporting and met at a weekly huddle.
Kane et al.	Patient flow	Nursing bed managers, transfer line operators, patient pathway coordinators	A tertiary care hospital in Baltimore, USA	"A systems engineering approach" involving a steering group consisting of hospital CEO, CIO, COO, VP for medical affairs, Director of nursing, and project leaders. Involved working with external supplies and use of DES and ABS.	Governance structure and core leadership team set up for project, medical director playing a key leadership role. Core leadership group met weekly and drive strategic operational initiatives. There is also a dedicated data analytics team and a group of clinical representatives. Also involves partnership with GE Healthcare.	Not clear – it seems project started in 2014, various interventions implemented from 2014/15, 2016/17, 2018 and ongoing. Reported results based on preliminary data Entire project seems to have lasted 4 years	Can't tell	Specifically targeting patient flow throughout the hospital 'system'. Considers the context / wider system (e.g. outside treatment facilities). Considers key stakeholders, particularly in governance of the new system (see governance structure). Actively explores risks through two different types of complex simulation modelling.	Key stakeholders identified and then brought together to develop the command centre jointly. A new space was created so that key stakeholders could be physically collocated, SOPs created and then simulation modelling performed. Evaluation is still underway.

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Table 2 – Characteristics of study cont. [Design, and other quality issues]

Study	Study Design	Baseline type (Prospective – study data OR Retrospective-routine data	Blinding of outcome measure (Yes, No, Can't Tell)	Funding source
Afsar-manesh et al., 2016[2]	Before, During & After	Retrospective routine data	Can't Tell?	No external funding
Bhatt et al., 2014[16]	Before, During & After	Retrospective routine data & Prospective study data	Can't Tell?	Lead author funded by hospital
Bhutani et al., 2006[15]	Before, During & After	Prospective study data	Can't Tell?	Eglin fund and the New-born Paediatric Research Fund
Bradley et al., 2011[14]	Before, During & After	Retrospective routine data	Can't Tell?	The Children's Investment Foundation Fund
Catchpole et al., 2014[13]	Before, During & After	Retrospective routine data & Prospective study data	No	Telemedicine and Advanced Technology Research Centre of the US Department of Defence
Dennerlein et al., 2017[17]	Before, During & After	Retrospective routine data	Can't Tell?	National Occupational for Safety and Health for the Harvard T.H. Chan School of Public Health Centre for Work, Health and Wellbeing; National Institute of Arthritis and Musculoskeletal and Skin Disease of the National Institute of Health; Partners HealthCare
Hathout et al., 2013[19]	Before, During & After	Prospective study data	Can't Tell?	Not reported
Heymann et al., 2004[18]	Before, During & After	Retrospective routine data & Prospective study data	Can't Tell?	Not reported. Note – lead author works for HMO, programme evaluated by HMO
Huntington et al., 2012[22]	Before, During & After /Concurrent Control	Retrospective routine data	Can't Tell?	World Bank; Manila Country Office; Department of Reproductive Health and Research, WHO, Geneva
Hwang et al., 2017[6]	Before, During & After	Retrospective routine data	Can't Tell?	One author received grants from College of Medicine, Korea University and the Korea Centres for Disease Control and Prevention.
Kottke et al., 2016[21]	Before, During & After	Retrospective routine data	Can't Tell?	National Heart and Lung Institute, National Institutes of Health, Bethesda, MD. Grant #R18HL096563 was the sole financial support for this project.
Lick et al., 2011[8]	Before, During & After	Retrospective routine data and Prospective study data	No	Funding support from Medtronic Foundation, Medtronic Corporation, the CentraCare Health Foundation and the Unity and Mercy Hospital Foundations
Loh et al., 2017[5]	Before, During & After	Retrospective routine data	No	Not reported
McKetta et al., 2016[7]	Before , During & After	Retrospective routine data & Prospective study data	Can't Tell	Not reported

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New et al., 2016[11]	Before, During & After /Concurrent Control	Prospective study data	Can't Tell	NIHR Programme Grant for Applied Research (RP-PG-0108-10020)
Rateb et al., 2011[10]	Before, During & After	Retrospective routine & Study data	Can't Tell	Not reported
Rothemich et al., 2010[12]	Concurrent Control (RCT)	Prospective study data	No	Funded by grant from the Agency for Healthcare Research and Quality (AHRQ) (5R21HS014854-02). One author owns stock in a Quitline service provider.
Rustagi et al., 2016[1]	Before, During & After /Concurrent Control (RCT)	Retrospective routine & Study data	Can't Tell	Funded by Eunice Kennedy Shriver National Institute of Child Health and Human Development, the National Institute of Allergy and Infectious Diseases, the National Cancer Institute, the National Institute on Drug Abuse, the National Heart, Lung and Blood Institute and the National Institute on Aging of the US National Institutes of Health under award numbers R01HD075057 and P30AI027757 (awarded to the University of Washington Center for AIDS Research), as well as the Doris Duke Charitable Foundation's African Health Initiative (awarded to K.S. and M.F.C.), and the Fogarty International Center grant number K01TW009207 (awarded to K.S.).
Ryan et al., 2006[9]	Before, During & After	Retrospective routine data	Can't Tell	Funded by grant from Turning Point
Shultz et al., 2015[4]	Before, During & After/Concurrent Control	Retrospective routine data	Can't Tell	Not reported
Tetuan et al., 2017[3]	Before, During & After	Prospective study data	Yes, for medication errors	Not reported
Allaudeen et al.	Before, During and After/ Concurrent Control	Retrospective routine data	Can't tell	Not reported
Anderson et al.	Before, During and After	Retrospective routine data	Can't tell	Not reported
Bell et al.	Before, During and After	Retrospective routine data	Can't tell	This article presents independent research funded by the NIHR School for Public Health Research (SPHR). NIHR SPHR is a partnership between the Universities of Sheffield, Bristol, Cambridge, Exeter, University College London; The London School for Hygiene and Tropical Medicine; the LiLaC collaboration between the Universities of Liverpool and Lancaster; and Fuse, the Centre for Translational Research in Public Health, a collaboration between Newcastle, Durham, Northumbria, Sunderland and Teesside Universities. Fuse is a UK Clinical Research Collaboration (UKCRC) Public Health Research Centres of Excellence, which receives funding from the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, and the National Institute for Health Research.
Bowen et al.	Before, During and After	Retrospective routine & Prospective Study data	Can't tell	Not reported
Cochran et al.	Before, During and After	Retrospective routine data	Can't tell	Not reported

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DeFlitch et al.	Before, During and After	Retrospective routine data	Can't tell	Received no financial support for the research authorship, and/or publication of this article.
Gupta et al.	Before, During and After	Retrospective routine data	Can't tell	Not reported
Hultman et al.	Before, During and After	Retrospective routine data	Can't tell	Not reported
Khan et al.	Before, During and After	Prospective Study data	Yes Yes	This project was supported by grant CER-1306-03556 from the Patient-Centered Outcomes Research Institute (principal investigator: CPL). AK was supported by grant K12HS022986 from the Agency for Healthcare Research and Quality (principal investigator: Jonathan Finkelstein; Boston Children's Hospital, Boston, MA). JDB was supported by grant 5T32HS00063-21 from the Agency for Healthcare Research and Quality (principal investigator: Jonathan Finkelstein). The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the report; or in the decision to submit the article for publication. Researchers were independent from funders and all authors had full access to the data and can take responsibility for the integrity of the data and the accuracy of the data analysis.
McGrath et al.	Before, During and After/ Concurrent Control	Retrospective routine & Prospective Study data	Can't tell	Agency for Healthcare Research & Quality (AHRQ)
Moran et al.	Before, During and After	Retrospective routine data	No	Performed independently without external funding
Srinivasan et al.	Before, During and After	Retrospective routine data	Can't tell	National Institutes of Health Clinical and Translational Science Award grant UL1 TR000448
Chandrasekar et al.	Before, During and After	Retrospective routine data	Can't tell	Not reported
Kane et al.	Before, During and After	Retrospective routine data*	Can't tell	Not reported

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Table 3a – Numbers and numerical values – Patient outcomes: Studies with Before, During & After Designs

Study	Outcomes measures	After	During	Before	P-values
Afsar-manesh et al., 2016[2]	Overall 30-day readmission rate Subgroups: General Medicine General Surgery Neurosurgery Paediatrics Orthopaedics	11.3%, [n or N not reported] 16.7% 7.8% 7.4% 9.8% 6.8%	- - - - - -	12.1%, [n or N not reported] 17.9% 9.9% 9.6% 10.8% 8.0%	*P*< 0.05 *P*< 0.05 *P*< 0.05 *P*< 0.05 *P*< 0.05 *P*< 0.05
Bhatt et al., 2014[16]	-	-	-	-	-
Bhutani et al., 2006[15]	Readmission rates for intensive phototherapy – n/N (%) [Rates estimated from graph. "Before" rate is for 1998. 1994-95 values available] Extreme hyperbilirubinemia	19/3,227 (0.59%) 0	27/3,168 (0.85%) 0	94/8,186 (1.15%) 0	- -
Bradley et al., 2011[14]	-	-	-	-	-
Catchpole et al., 2014[13]	-	-	-	-	-
Dennerlein et al., 2017[17]	-	-	-	-	-
Hathout et al., 2013[19]	Patients on recommended treatment	70%, n or N not reported	-	55%, n or N not reported	-
Heymann et al., 2004[18]	-	-	-	-	-
Huntington et al., 2012[22]	Number of maternal deaths/yr at intervention site– n/N (%) Maternal Mortality Rate (MMR)	18/*15,789* (0.114%) 114	24 [N not reported]	42/*16,535* (0.254%) 254	Not reported
Hwang et al., 2017[6]	Good neurologic recovery at discharge (CPC 1, 2) –n/N (%) Number of patients admitted to ICU – n/N (%) Successful TH in cases of comma – n/N (%) Discharged from hospital alive – n/N (%)	24/282 (8.5%) 101/282 (35.8%) 33/96 (34.4%) 51/282 (18.1%)	5/117 (4.3%) 31/117 (26.6%) 2/31 (6.5%) 15/117 (12.8%)	6/182 (3.3%) 29/182 (15.9) 1/27 (3.7%) 16/182 (8.8%)	*p=0.001* *p*<0.001 *p*<0.001 <0.05
Kottke et al., 2016[21]	Coronary Heart Disease: Composite Score (Rates of patients meeting composite goals for CHD (blood pressure <140/90 mmHg, low-density lipoprotein cholesterol level < 100				

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	mg/dl, tobacco-free, and using aspirin unless contraindicated)) – n/N (%)		-	*206*/511 (40.3%)	*<0.0001*
	Coronary Heart Disease: Aspirin compliance – n/N (%)	*317*/529 (59.9%)	-	*333*/511 (65.2%)	*<0.0001*
	Diabetes: Aspirin compliance – n/N (%)	*516*/529 (97.5%)	-	*284*/485 (58.6%)	*<0.0001*
	Diabetes: Composite score Proport to diabetic patients (meeting CHD goal plus haemoglobin A_{1c} concentration <8%) – n/N (%)	*497*/509 (97.6%)	-	*119*/485 (24.5%)	*<0.0001*
	Proportion of patients satisfied or very satisfied with preventive services received – n/N (%)	*231*/509 (45.4%)	-	*362*/455 (79.6%)	*Not significant*
	Providers satisfied or very satisfied with preventive services – n/N (%)	*296*/320 (92.4%)	-	*137*/231 (59.5%)	*p=0.0017*
		152/205 (74.3%)			
Lick et al., 2011[8]	Survival to hospital discharge of all patients after out-of-hospital cardiac arrest – n/N (%)	48/247 (19%)	-	9/106 (8.5%)	*p=0.011*
Loh et al., 2017[5]	-	-	-	-	-
McKetta et al., 2016[7]	-	-	-	-	-
New et al., 2016[11]	90-day readmissions – n/N (%)	102/*567* (18%)	-	94/*470* (20%)	*p=0.3000*
	Complications – n/N (%)	70/*583* (12%)	-	47/*470* (10%)	*p=0.070*
Rateb et al., 2011[10]	Percentage of satisfied customers with:				
	Medical services - n/N (%)	*216*/251 (86%)	-	*22*/63 (34.3%)	*P*<0.001
	Housekeeping - n/N (%)	*225*/251 (89.7%)	-	*21*/63 (34%)	*P*<0.001
	Staff communication - n/N (%)	*231*/251 (91.9%)	-	*18*/63 (31.3%)	*P*<0.001
	Accessibility - n/N (%)	*215*/251 (85.8%)	-	*19*/63 (30%)	*P*<0.001
Rustagi et al., 2016[1]	Proportion of HIV-positive pregnant women who received antiretroviral medications – n/N (%):	Overall - *13*/17 (77.7%)	-	Overall - *12*/18 (66.45%)	*p*=0.36
	Cote d'Ivoire	100%, N = 5	-	79.2%, N = 6	*p*=0.62
	Kenya	73.4%, N = 6	-	52.5%, N = 6	*p*=0.02
	Mozambique	63.5%, N = 6	-	67.6%, N = 6	*p*=0.23
	Mean proportion of HIV-exposed infants who received an HIV CPR screening test by 6 or 8 weeks of age:	Overall mean=46.1%, N=18	-	Overall mean=34.5%, N = 18	*p*=0.25
	Cote d'Ivoire	51.2%, N = 6	-	36.0%, N = 6	*p*=0.57
	Kenya	41.5%, N = 6	-	44.5%, N = 6	*p*=0.88

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	Mozambique	46.3%, N = 6	-	23.35%, N = 6	*p*=0.04
Ryan et al., 2006[9]	Severity of Alcohol Dependence Questionnaire (SADQ) score – n/N (%):				
	Mild/Moderate:				
	Planned discharge	721/977 (73.8%)	-	124/191 (64.9%)	*P<0.012*
	Unplanned discharge	256/977 (26.2%)	-	67/191 (35.1%)	
	Severe:				
	Planned discharge	1965/*2,748* (71.5%)	-	102/*164* (62.0%)	*P<0.008*
	Unplanned discharge	785/*2,754* (28.5%)	-	65/*171* (38.0%)	
	Housing – n/N (%):				
	Stable:				
	Planned discharge	2340/3,233 (72.4%)	-	787/1,168 (67.4%)	*P<0.001*
	Unplanned discharge	893/3,233 (27.6%)	-	381/1,168 (32.6%)	
	Unstable:				
	Planned discharge	390/572 (68.2%)	-	243/395 (61.5%)	*P<0.032*
	Unplanned discharge	182/572 (31.8%)	-	152/395 (38.5%)	
Shultz et al., 2015[4]	-	-	-	-	-
Tetuan et al., 2017[3]	-	-	-	-	-
Allaudeen et al.	-	-	-	-	-
Anderson et al.	Laboratory evaluation for secondary causes of osteoporosis - n/N (%):				
	Completed blood cell count	116/117 (99%)	-	154/154 (100%)	*p=1.000*
	Basic metabolic panel with calcium	111/117 (95%)	-	151/154 (98%)	*p=0.963*
	Hepatic function panel	104/117 (89%)	-	74/154 (48%)	*p<0.001*
	25-hydroxyvitamin D	104/117 (89%)	-	105/154 (68%)	*p<0.001*
	Pharmacotherapy on discharge - n/N (%):				
	Calcium	116/117 (99%)	-	84/154 (55%)	*p<0.001*
	Vitamin D	112/117 (96%)	-	107/154 (70%)	*p<0.001*
	Antiosteoporosis	70/117 (85%)	-	34/154 (24%)	*p<0.001*
	Follow-up appointment completed within 30 days- n/N (%):				
	PCP (Internal to system)	13/117 (45%)	-	14/154 (26%)	*p=0.363*
	Metabolic Bone Clinic	32/117 (28%)	-	4/154 (3%)	*p<0.001*
	Orthopedics Clinic	96/117 (82%)	-	118/154 (77%)	*p=0.175*
Bell et al.	Probability of quitting smoking by delivery date:				
	Adjusted Odds Ratio (95% CI)	1.81 (1.54 to 2.12)	-	0.13 (0.09 – 0.19)	*p<0.001*

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Bowen et al.	-	-	-	-	-
Cochran et al.	Patient satisfaction with quality of care Percent of patients leaving without treatment	41st percentile [n or N not reported] 0.26%, [n or N not reported]	- - 	20th percentile [n or N not reported] 1.50%, [n or N not reported]	*not reported* *not reported*
DeFlitch et al.	Left without being seen Patient satisfaction	0.6%,[n or N not reported] 85th percentile [n or N not reported]	- -	5.7%, [n or N not reported] 17th percentile [n or N not reported]	*p<0.0001* *p<0.0001*
Gupta et al.	-	-	-	-	-
Hultman et al.	Partial or total flap loss – n/N (%) Take-back rates – n/N (%) Overall complication rates	*3*/46 (7%) *11*/46 (23.9%) *14*/46 (30%)	*3*/27 (11%) *6*/27 (20.7%) *9*/27 (33.3%)	*1*/39 (3%) *8*/39 (20.5%) *14*/39 (35.9%)	*Not significant* *Not significant* *Not significant*
Khan et al.	Family experience during rounds – top-box scores(95%CI): Understood what was said on rounds Medical team explained well possible changes to child's condition Satisfied with opportunity to ask questions on rounds Medical team listened to family concerns Family was included in decision making Family felt important in their role on rounds Family respectfully spoken to on rounds Quality of communication during morning rounds Family experience after rounds - top-box scores(95%CI): Satisfaction with frequency of updates on child Quality of update explanations Inclusion in decision making later in day Written communication - top-box scores(95%CI): Frequency of written updates Understood written updates provided Communication with doctors - top-box scores(95%CI): Shared understanding with doctors of medical plan Doctors addressed family concerns Doctors made family feel an important part of healthcare team	N = 890 62.8% (53.7% - 71.1%) 59% (?) 72% (?) 72% (?) 59% (?) 57% (?) 79% (?) 66% (?) N = 890 54% (?) 60% (?) 55% (?) N = 890 33.7% (23.9% - 45.2%) 57.9% (46.4% - 68.6%) N = 890 59.2% (49.9% - 67.8%) 65.9% (56.8% - 73.8%) 60.9% (49.2% - 71.4%)	- - - - - - - - - - - - - - - -	N = 947 53.9% (44.6% - 63.0%) 56% (?) 69% (?) 67% (?) 56% (?) 50% (?) 78% (?) 62% (?) N = 947 49% (?) 58% (?) 53% (?) N = 947 15.6% (8.9% - 25.9%) 46.5% (34.2% - 59.3%) N = 947 54.0% (44.6% - 63.1%) 61.8% (52.5% - 70.3%) 57.7% (45.9% - 68.7%)	 *p=0.03* *not available* *not available* *not available* *not available* *not available* *not available* *not available* *not available* *not available* *not available* *p<0.001* *p=0.04* *p=0.14* *p=0.22* *p=0.34*

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	Communication with nurses - top-box scores(95%CI):	N = 890		N = 947	
	Shared understanding with nurses of medical plan	65.4% (58.4% - 71.8%)	-	55.3% (48.0% - 62.4%)	*p=0.02*
	Nurses addressed family concerns	70.2% (62.9% - 76.6%)	-	61.2% (53.4% - 68.5%)	*p=0.02*
	Nurses made family feel an important part of healthcare team	70.7% (61.4% - 78.6%)	-	63.2% (53.5% - 71.9%)	*p=0.04*
	Teamwork amongst providers - top-box scores(95%CI):	N = 890		N = 947	
	Teamwork amongst doctors and nurses	62% (?)	-	59% (?)	*not available*
	Understanding - top-box scores(95%CI):	N = 890		N = 947	
	Understood overall reason for child's hospital stay	72% (?)	-	72% (?)	*not available*
	Understood what needed before child can return home from hospital	66% (?)	-	62% (?)	*not available*
	Overall quality - top-box scores(95%CI):	N = 890		N = 947	
	Overall quality of child's care	73% (?)	-	69% (?)	*not available*
	Quality of communication during hospital stay	59% (?)	-	55% (?)	*not available*
	Overall medical errors:				
	n/N (%)	245/1532 (*16%*)	-	259/1574 (*16.5%*)	
	Rate/1000 patient days (95%CI)	35.8 (26.9 – 47.7)	-	41.2(31.2 – 54.5)	*p=0.21*
	Non-harmful errors:				
	– n/N (%)	164/1532 (*10.7%*)	-	139/1574 (*8.8%*)	
	Rate/1000 patient days (95%CI)	22.0 (15.1 – 32.1)	-	20.0 (13.2 – 30.2)	*p=0.50*
	Harmful (preventable adverse events):				
	– n/N (%)	81/1532 (*5.3%*)	-	120/1574 (*7.6%*)	
	Rate/1000 patient days (95%CI)	12.9 (8.9 – 18.6)	-	20.7 (15.3 – 28.1)	*p=0.01*
	Non-preventable adverse events:				
	n/N (%)	31/1532 (*2%*)	-	72/1574 (*4.5%*)	
	Rate/1000 patient days (95%CI)	5.2(3.1 – 8.8)	-	12.6(8.9 – 17.9)	*p=0.003*
McGrath et al.	-	-	-	-	-
Moran et al.	Care processes in hospitals with consistent submissions (patients with ISS ≥ 9):				
	Seen by consultant in ED, year-n/N (%)	16/17 – 10,943/19,197 (63%) 15/16 – 9,876/18,151 (61%) 14/15 – 8,963/16,414 (60%) 13/14 – 8,103/14,793 (60%)	12/13 – 6,169/11,708 (58%) 11/12 – 4,250/9679 (47%)	10/11–3,183/8626 (39.3%) 09/10–2,103/6957 (32%) 08/09–1,504/5338 (29%)	*Not reported*

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	Intubated in ED, n (%)	2016/17 – 1,917 (11%) 2015/16 – 1,959 (12%) 2014/15 – 1,845 (12.4%) 2013/14 – 1,778 (13.2%)	2012/13 – 1,460 (13.7%) 2011/12 – 1,198 (13.3%)	2010/11 – 1,098 (13.6%) 2009/10 – 918 (13.6%) 2008/09 – 701 (13.6%)	*Not reported*
	Treated at MTC, n (%)	2016/17 – 14,247 (82%) 2015/16 – 13,279 (82%) 2014/15 – 11,873 (80%) 2013/14 – 10,790 (80%)	2012/13 – 8,212 (77%) 2011/12 – 6,750 (75%)	2010/11 – 6,113 (75%) 2009/10 – 5,058 (75%) 2008/09 – 3,757 (73%)	*Not reported*
	Blood given within 6h, n (%)	2016/17 – 423 (2.2%) 2015/16 – 470 (2.6%) 2014/15 – 405 (2.5%) 2013/14 – 391 (2.6%)	2012/13 – 372 (3.2%) 2011/12 – 259 (2.7%)	2010/11 – 283 (3.3%) 2009/10 – 270 (3.9%) 2008/09 – 118 (2.2%)	*Not reported*
	TXA if blood given, n (%)	2016/17 – 382 (90%) 2015/16 – 426 (91%) 2014/15 – 365 (90%) 2013/14 – 323 (83%)	2012/13 – 236 (63%) 2011/12 – 60 (23%)	2010/11 – 7 (2.5%) 2009/10 – 0 (0%) 2008/09 – 0 (0%)	*Not reported*
	Survival at discharge, n (%)	2016/17 – 17,451 (91%) 2015/16 – 16,424 (91%) 2014/15 – 14,878 (91%) 2013/14 – 13,388 (91%)	2012/13 – 10,568 (90%) 2011/12 – 8,808 (91%)	2010/11 – 7,895 (92%) 2009/10 – 6,313 (91%) 2008/09 – 4,891 (92%)	*Not reported*
	Time to death, median (IQR)	2016/17 – 8 (4-14) 2015/16 – 8 (4-14) 2014/15 – 8 (4-14) 2013/14 – 8 (4-13)	2012/13 – 7 (4-13) 2011/12 – 8 (4-13)	2010/11 – 8 (4-13) 2009/10 – 8 (4-14) 2008/09 – 8 (5-14)	*Not reported*
	Care process in <u>all hospitals (patients with ISS ≥ 9)</u>:				
	Intubated by Dr prehospital, n (%)	2016/17 – 44 (0.1%) 2015/16 – 73 (0.2%) 2014/15 – 99 (0.3%) 2013/14 – 80 (0.3%)	2012/13 – 73 (0.3%) 2011/12 – 41 (0.2%)	2010/11 – 80 (0.5%) 2009/10 – 80 (0.7%) 2008/09 – 50 (0.6%)	*Not reported*
	Seen by consultant in ED, n (%)	2016/17 – 18,797 (46.2%) 2015/16 – 17,691 (45.3%) 2014/15 – 16,111 (46.3%) 2013/14 – 14,406 (46.3%)	2012/13 – 11,531 (43.7%) 2011/12 – 7,601 (34.6%)	2010/11 – 5,217 (30.5%) 2009/10 – 3,218 (27.3%) 2008/09 – 2,188 (25%)	*Not reported*
	Seen by consultant in ED if ISS >15, n (%)	2016/17 – 9,412 (56.8%) 2015/16 – 8,876 (56.4%) 2014/15 – 7,942 (57.8%) 2013/14 – 7,044 (57.7%)	2012/13 – 5,552 (54.8%) 2011/12 – 3,825 (43.7%)	2010/11 – 2,712 (38.2%) 2009/10 – 1,713 (34.6%) 2008/09 – 1,136 (31.9%)	*Not reported*
	Seen by consultant in ED if GCS <13, n (%)	2016/17 – 2,724 (76%) 2015/16 – 2,755 (74.8%)	2012/13 – 1,981 (72.9%) 2011/12 – 1,338 (62%)	2010/11 – 1,027 (58%) 2009/10 – 664 (52.2%)	*Not reported*

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		2014/15 – 2,558 (74.6%) 2013/14 – 2,384 (75.4%)		2008/09 – 459 (47.4%)	
	Intubated in ED, n (%)	2016/17 – 2,929 (7.2%) 2015/16 – 2,976 (7.6%) 2014/15 – 2,850 (8.2%) 2013/14 – 2,700 (8.7%)	2012/13 – 2,386 (9%) 2011/12 – 1,898 (8.6%)	2010/11 – 1,639 (9.6%) 2009/10 – 1,248 (10.6%) 2008/09 – 951 (10.9%)	*Not reported*
	Survival at discharge, year-n/N (%)	16/17–40407/44059 (91.7%) 15/16–38733/42371 (91.4%) 14/15–34558/37725 (91.6%) 13/14–30808/33647 (91.6%)	12/13–25829/28239 (91.5%) 11/12–21385/23211 (92.1%)	10/11–16535/17956 (92.1%) 09/10–11129/12123 (91.8%) 08/09–8245/8903 (92.6%)	*Not reported*
	TXA given, year-n/N (%)	16/17–3,041/44069 (6.9%) 15/16–3,633/42371 (8.6%) 14/15–3,092/37725 (8.2%) 13/14–2,511/33647 (7.5%)	12/13–1217/28239 (4.3%) 11/12–304/23211 (1.3%)	10/11–24/17956 (0.1%) 09/10–1/12123 (0%) 08/09–2/8903 (0%)	*Not reported*
	Blood given within 6h, year-n/N (%)	16/17–672/44069 (1.5%) 15/16–810/42371 (1.9%) 14/15–714/37725 (1.9%) 13/14–633/33647 (1.9%)	12/13–639/28239 (2.3%) 11/12–396/23211 (1.7%)	10/11–374/17956 (2.1%) 09/10–333/12123 (2.7%) 08/09–174/8903 (2%)	*Not reported*
	TXA and blood given within 6h, year-n/N (%)	16/17–601/44069 (89.4%) 15/16–717/42371 (88.5%) 14/15–616/37725 (86.3%) 13/14–485/33647 (76.6%)	12/13–394/28239 (61.7%) 11/12–89/23211 (22.5%)	10/11–7/17956 (1.9%) 09/10–1/12123 (0.3%) 08/09–1/8903 (0.6%)	*Not reported*
	Time to death within 30 days, year-median (IQR), N	16/17–8 (4-14), 44069 15/16–8 (4-14), 42371 14/15–8 (4-14), 37725 13/14–8 (4-13), 33647	12/13–7 (4-13), 28239 11/12–8 (4-13), 23211	10/11–8 (4-13), 17956 09/10–8 (4-14), 12123 08/09–8 (5-14), 8903	*Not reported*
Srinivasan et al.	Rate of NG hydration – n/N (%)	53/91 (58%)	53/91 (58%)	0/221 (0%)	*Not reported*
	Primary outcome measure NG tube placed for hydration – n/N (%)	53 (58%)		0 (0%)	-
	Rate of NG complications Aspiration- n/N (%) Death - n/N (%) Epistaxis - n/N (%) Displacement/removal - n/N (%)	n = 53 0/53 (0%) 0/53 (0%) 0/53 (0%) 17/53 (32%)		 0/221 (0%) 0/221 (0%) 0/221 (0%) 0/221 (0%)	
Chandrasekar et al.	Reduction in in-hospital AKI mortality pre – post project 30-day mortality rate for AKI patients	23.2% 25.9% decrease	-	Data not given Data not given	*P<0.0001*

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Kane et al.	-	-	-	-	-

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Table 3b – Numbers and numerical values – Patient outcomes: Studies with Concurrent Control Designs

Study	Outcomes measures	Intervention	Control 1	Control 2	Control 3	P-values
Huntington et al., 2012[22]	Percentage of births delivered in health facilities per year	72%, n=7,017	46%, n=Not provided	33%, n=Not provided	28%, n=Not provided	-
	Number of maternal deaths per year – n/N (%) [showing best three of five controls]	18/*15,789* (0.114%)	9, n=Not provided	11, n=Not provided	16, n=Not provided	-
New et al., 2016[11]	90-day readmissions – n/N (%)	102/*567* (18%)	55/*306* (18%)	-	-	*p=0.3000*
	Complications – n/N (%)	70/*583* (12%)	32/*320* (10%)	-	-	*p=0.070*
Rothemich et al., 2010[12]	-	-	-	-	-	-
Shultz et al., 2015[4]	Number of patients receiving Tdap vaccination-n/N (%):					
	Follow-up	6,978/14,748 (47.3%)	4 343/14,395 (30.2%)	-	-	*p<0.001*
	Intervention year	12,267/22,565 (54.4%)	3 806/17,043 (22.3%)			
	Base-line	3,976/25,584 (15.5%)	2 623/18,587 (14.1%)			
	Number of patients receiving flu vaccination-n/N (%):					
	Follow-up	4 417/14,748 (30.0%)	6 743/14,395 (46.8%)	-	-	*p<0.001*
	Intervention year	9 301/22,565 (41.2%)	8 197/17,043 (48.1%)			
	Base-line	6 867/25,584 (26.8%)	6 738/18,587 (36.3%)			
Rustagi et al., 2016[1]	Mean proportion of HIV-positive pregnant women who received antiretroviral medications:	Overall mean=77.7%, N = 17	Overall mean=65.9%, n=17	-	-	-
	Cote d'Ivoire	100%, N = 5	100%, n=5	-	-	-
	Kenya	73.4%, N = 6	38.5%, n=6	-	-	-
	Mozambique	63.5%, N = 6	64.9%, n=6	-	-	-
	Mean proportion of HIV-exposed infants who received an HIV CPR screening test by 6 or 8 weeks of age:	Overall mean=46.1%, N = 17	Overall mean=32.0%, N = 17	-	-	-
	Cote d'Ivoire	51.2%, N = 5	42.6%, N = 6	-	-	-
	Kenya	41.5%, N = 6	19.2%, N = 5	-	-	-
	Mozambique	46.3%, N = 6	32.1%, N = 6	-	-	-
Allaudeen et al.	-	-	-	-	-	-
McGrath et al.	-	-	-	-	-	-

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Table 4a – Numbers and numerical values – Service, Resource or Cost outcomes: Studies with Before, During & After Designs

Study	Outcomes measures	After	During	Before	P-values
Afsar-manesh et al., 2016[2]	-	-	-	-	-
Bhatt et al., 2014[16]	Operating Room (OR) Turnover Time (TT)	mean=23m35s (SD=5m52s), n=17 (in Orthopaedic and vascular surgery only)	-	mean=38m51s, (SD=14m39s), n=13 (Orthopaedic and vascular surgery only)	*p*< 0.001
	Incidence of turnover time greater than or equal to 30 minutes – n/N (%)	*2*/17 (11.7%)	-	*9*/13 (69.2%)	*Not reported*
Bhutani et al., 2006[15]	Use of hospital-based intensive phototherapy – n/N (%)	156/11,995 (1.3%)	159/6,395 (2.49%)	446/8,186 (5.44%)	-
	Use of exchange transfusion	1(1 in 11,995 well babies)	2(1 in 3,198 well babies)	5(1 in 1,637 well babies)	-
	Never events (TSB level greater than 30mg/dl)	0	0	0	-
	Close calls (TSB level greater than or equal to 25mg/dl)	1 in 15,000	-	1 in 625	-
Bradley et al., 2011[14]	Antenatal care coverage – n/N (%)	140/140 (100%) $\beta = 41.4$, $R^2 = 0.55$	-	56/140 (40%)	*P<0.002*
	Skilled birth attendant coverage – n/N (%)	14/140 (10%) $\beta = 2.6$, $R^2 = 0.50$	-	7/140 (5%)	*p=0.015*
	Antenatal care HIV testing coverage	119/140 (85%) $\beta = 26.1$, $R^2 = 0.54$	-	70/140 (50%)	*p<0.001*
	Health post and health centre HIV testing coverage	$\beta = 2.7$, $R^2 = 0.39$	-	-	*p<0.001*
	Average outpatient visit at health centres	$\beta = 0.4$, $R^2 = 0.65$ N= 10 health centres	-	-	*p=0.276*
Catchpole et al., 2014[13]	Number of flow disruptions in Computed tomography (CT): High level trauma	mean=18.5 (SD=18.6, Range=1-50), median=9.00, n=13	-	mean=25.6 (SD=32.4, Range=1-105), median=13.5, n=14	-
	Low level trauma		-		-

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	Time in the emergency department (ED) in minutes:	mean=9.60 (SD=6.32, Range=1-27), median=8.00, n=107		mean=9.80 (SD=7.89, Range=1-65), median=8.00, n=72	
	High level trauma	mean=123 (SD=76.1, Range=39-250), median=85, n=13	-	mean=127 (SD=67.9, Range=38-291), median=119, n=14	-
	Low level trauma	mean=80 (SD=52.5, Range=13-335), median=70, n=107	-	mean=96 (SD=55.9, Range=18-347), median=84, n=72	p=0.01
	Length of Stay (LoS) in days:				
	Cohort with Major Risk of Mortality	Kruskal-Wallis test: LoS = 69 (z=-2.49), n=508 median=5	-	Kruskal-Wallis test: LoS = 74, n=510, median=8	-
	Cohort with Extreme Risk of Mortality	LoS=25, median=8	-	LoS= 33, median=8	
Dennerlein et al., 2017[17]	All injuries – n/N (%)	388/2131 (18.2%)	-	448/2149 (20.8%)	-
	Body part affected - Neck/Shoulder pain:				
	Count – n/N (%)	43/2131 (2.0%)	-	64/2149 (3%)	*p<0.05*
	Rate/100FTEs (95% CI)	2.0 (1.5 – 2.7)	-	3.0 (2.3 – 3.8)	
	Rate Ratio (95% CI)	0.678 (0.46 – 1.00)			
	Cause of injury - Lifting/exertion injuries				
	Count – n/N (%)	174/2131 (8.1%)	-	239/2149 (11.1%)	*p<0.05*
	Rate/100FTEs (95% CI)	8.2 (7.0 – 9.5)	-	11.1 (9.8 – 12.6)	
	Rate Ratio (95% CI)	0.73 (0.60 – 0.89)			
	Nature of injury - Pain and inflammation				
	Count – n/N (%)	119/2131 (5.6%)	-	153/2149 (7.1%)	*p<0.05*
	Rate/100FTEs (95% CI)	5.6 (4.7 – 6.7)	-	7.1 (6.1-8.3)	
	Rate Ratio (95% CI)	0.78 (0.62 – 1.00)			
Hathout et al., 2013[19]	Time from referral to sleep study	Median = 125 days, [n or N not reported]	-	Median=600 days	-
	Days to treatment starting after prescription generated	21 days	-	90 days	-
	Wait for treatment after study	21 days	-	180 days	-
	Annual studies	4,289	-	1,347	
Heymann et al., 2004[18]	Per-visit antibiotic purchasing for influenza visits	58.1 per 1000 visits	-	79.2 per 1000 visits	*p<0.0001*

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Huntington et al., 2012[22]	Percentage of births delivered in health facilities per year	72%, [n or N not reported]	35%, [n or N not reported]	28%, [n or N not reported]	-
	Volume of blood supplies received (as a proxy indicator for improvements in availability of essential medical products for maternal health services)	983 units	355 units	36 units	-
Hwang et al., 2017[6]	Proportion of Out-of-Hospital cardiac arrest patients receiving all CPR delivery enhancements	*24*/282 (8.5%)	*3*/117 (2.6%)	*1*/182 (0.5%)	*P<0.0001*
	Percentage of bystander CPRs without dispatcher assistance	*78*/282 (27.7%)	*32*/117 (27.4%)	*24*/182 (13.2%)	*Not reported*
	Proportion of no documented arrest rhythm by EMS	*0*/282 (0.0%)	*4*/117 (3.4%)	*11*/182 (6.0%)	*p=0.004*
	Percentage of ACLS under capnography monitoring	*175*/282 (62.2%)	*64*/117 (55.1%)	*75*/182 (41.4%)	*p=0.008*
	Percentage of extracorporeal CPR	*29*/282 (10.5%)	*9*/117 (7.7%)	3/182 (1.4%)	*p=0.052*
	Percentage of successful therapeutic hypothermia in coma patients	*97*/282 (34.4%)	*8*/117 (6.5%)	*7*/182 (3.7%)	*p<0.001*
	Immediate coronary angiography for cases of presumed cardiac aetiology	*245*/282 (87.1%)	*67*/117 (57.1%)	*112*/182 (61.5%)	*p=0.005*
	Number of patients who were admitted to the ICU	101/282 (35.8%)	31/117 (26.5%)	29/182 (15.9%)	*p<0.001*
Kottke et al., 2016[21]	-	-	-	-	-
Lick et al., 2011[8]	Interval from 911 to advanced life support at the scene in minutes – mean (SD) N	7.2 (SD 3.6) N=247	-	7.5 (SD 3.5) N=106	*p=0.556*
	Bystander cardiopulmonary resuscitation-n/N (%)	*72*/247 (29%)	-	*21*/106 (20%)	*p=0.86*
	Impedance threshold device use – n/N (%)	*160*/247 (64.8%)	-	*9*/106 (8.5%)	-
	In-hospital treatment of cardiac arrest patients who survived to hospital admission-n/N (%):				
	In-hospital hypothermia	*44*/95 (46%)	-	0/37 (0%)	-
	Cardiac catheterization	*45*/95 (47%)	-	*8*/37 (22%)	*p<0.001*

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	Implantable cardiac Defibrillator placed	*24*/95 (25%)	-	*5*/37 (14%)	*p=0.17*
Loh et al., 2017[5]	Number of intraocular (IOL) lens errors-n/N (%)	10/39,390 (0.025%)	1/7,475 (0.013%)	3/6,111 (0.049%)	-
	Time between two IOL incidents	56 days	385 days	35 days	-
	Number of intraocular lens near miss error	140/39,390 (0.36%)	9/7,475 (0.12%)	36/6,111 (0.59%)	-
	Intraocular lens implant error rates	2.54 per 10,000 cases N=39,390	1.32 per 10,000 cases, N=7,475	4.91 per 10,000 cases, N=6,111	*Not stated*
McKetta et al., 2016[7]	Mean turnaround time in Catheterization labs in minutes – mean (SD) N	32 (SD 12) N= 138	-	55 (SD 34) N=135	*p<0.001*
New et al., 2016[11]	NOTECHS Mean (SD) – a measure of operating teams' non-technical skills	77.84 (SD 11.59) N= 25	-	73 (SD 7.1) N= 17	*p=0.938*
	WHO Time Out attempt – Component of WHO surgical safety checklist – n/N (%)	24/25 (96%)	-	17/17 (100%)	*p=1.000*
	WHO Time-Out complete compliance – number of cases in which all three components of Time-Out were completed – n/N (%)	9/25 (36%)	-	3/17 (18%)	*p=0.621*
	WHO Sign Out – number observed	1/25 (4%)	-	0/17 (0%)	*p=1.000*
	Glitch rate/hour – these are deviations from recognised processes with potential to reduce quality or speed – mean (SD) N	6.59 (SD 3.95) N= 25	-	7.85 (SD 2.69) N= 17	*p=0.098*
	Length of stay in days (SD)	7.7 (SD 15) N= 292	-	10.3 (SD 25) N= 224	*p=0.396*
Rateb et al., 2011[10]	Monthly customer flows-mean (SD) N	3,334.3 (SD 1,888.6) N= 6	-	1,747.3 (SD 1,932.4) N= 6	*p*<0.001
	Average customer compliance with booking system across six centres (%)	Mean=75.8%, N=6	-	Mean=52.1%, N=6	*p*<0.001
	Mean time spent per customer cycle in minutes (SD) N	18.3 (SD 5.5) N=212	-	48.8 (SD 14.5) N=63	*p*<0.001
	Appointment delays (days) - mean	6.2 days	-	18 days	-
	Percentage of satisfied staff with: Crowdedness	*101*/101 (100%)	-	*15*/36 (40.7%)	*p*<0.001

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	Process flow General satisfaction Administrative process Housekeeping Medical process Financial benefit	*100*/101 (99.2%) *100*/101 (99.1%) *100*/101 (98.6%) *99*/101 (98.5%) *99*/101 (98.4%) *94*/101 (93.0%)	- - - - - -	*15*/36 (42.6%) *16*/36 (44.4%) *13*/36 (37%) *12*/36 (32.4%) *15*/36 (40.7%) *12*/36 (33%)	*p*<0.001 *p*<0.001 *p*<0.001 *p*<0.001 *p*<0.001 *p*<0.001
Rustagi et al., 2016[1]	Mean proportion of pregnant women tested for HIV at antenatal care visit: Cote d'Ivoire Kenya Mozambique	Overall mean=95.9%, N=18 100%, N=6 96.0%, N=6 91.7%, N=6	- - - -	Overall mean=90.5%, N=18 94.2%, N=6 86.8%, N=6 90.6%, N=6	*p=0.97* *p=0.25* *p=0.30* *p=0.91*
Ryan et al., 2006[9]	-	-	-	-	-
Shultz et al., 2015[4]	Number of visits per patient for Tdap and flu vaccinations- mean (SD) N: Number of patients receiving Tdap vaccination – n/N (%) Number of patients receiving flu vaccination.	2.6 (SD 2.4) N = 39,882 *26,419*/67,914 (38.9%) *26,011*/67,914 (38.3%)	2.9 (SD 2.7) N = 39,822 *27,573*/67,914 (40.6%) *30,018*/67,914 (44.2%)	3.0 (SD 2.9) N = 39,882 *10,119*/67,914 (14.9%) *20,918*/67,914 (30.8%)	*Not stated* *Not stated* -
Tetuan et al., 2017[3]	Nurse workarounds – n/N (%) Safety Attitudes Questionnaire (SAQ) Score –mean (SD) N Systems Thinking Scale (STS) score-mean (SD) N Medication events – n/N (%) Workaround with time, dose or omission error – n/N (%)	175/1,998 (8.8%) 4.05 (SD 0.547) N = 334 64.90 (SD 8.5) N =334 84/1,998 (4.2%) 11/1,998 (6.3%)	- - - - -	305/1,652 (18.5%) 3.95 (SD 0.605) N = 585 63.39 (SD 9.36) N = 585 156/1,652 (9.4%) 13/1,652 (4.3%)	*P*< 0.0001 *P*= 0.029 *P*= 0.013 *p<0.001* *p=0.3276*
Allaudeen et al.	ED Length of Stay for medicine admissions, hrs- mean (SD) N Year 1 Year 2 Year 3	7.2 [n or N not reported] 7.9 7.1 6.4	-	8.7 [n or N not reported]	*P<0.001*
Anderson et al.	Hospital LOS in days – mean, median (SD) N Time to surgery in hours – mean, median (SD) N 30-day all-cause readmissions – n/N (%)	5.5, 5.0 (SD 2.22) N = 117 26.5, 22.3 (SD 17.5) N = 117 3/117 (2.7%)	- - -	6.4, 5.0 (SD 4.87) N = 154 29.0, 22.5 (SD 24.9) N = 154 5/154 (3.2%)	*p=0.004* *p=0.168* *p=0.520*

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	Disposition on discharge- n/N (%):				*p=0.244*
	Home with or without home healthcare	19/117 (16%)	-	33/154 (21%)	*p=0.244*
	Skilled nursing facility or nursing home	93/117 (79%)	-	105/154 (68%)	*p=0.244*
	Died	0/117 (05)	-	1/154 (1%)	*p=0.244*
	Other	5/117 (5%)	-	15/154 (10%)	
	Follow-up appointment scheduled before discharge – n/N (%):				*p=0.006*
	PCP (Internal or external to system)	33/117 (28%)	-	23/154 (15%)	*p<0.001*
	Metabolic Bone Clinic	62/117 (53%)	-	5/154 (3%)	*p=0.005*
	Orthopaedics Clinic	109/117 (93%)	-	126/154 (82%)	
Bell et al.	Referral rates for cessation service overall – Incidence Rate Ratio (95% CI)	2.47 (2.16 – 2.81)	-	-	-
Bowen et al.	Transmission error rates (of stroke alerts) via the pager system – n/N (%):				
	ED	*4*/88 (5.1%)		*30*/75 (40.0%)	*p=0.0001*
	NRR	*17*/88 (18.8%)		*17*/75 (22.7%)	*p=0.004*
	CR	*1*/88 (1.1%)		*9*/75 (12.0%)	*p=0.208*
Cochran et al.	Median length of stay per patient in minutes	162, [n or N not reported]	-	202, [n or N not reported]	*Not reported*
	Median door-to-doctor time	13, [n or N not reported]	-	27, [n or N not reported]	*Not reported*
DeFlitch et al.	Average waiting time in minutes	11 [n or N not reported]	-	66 [n or N not reported]	*p<0.0001*
	Door-to-doctor time- median (MAD*), N	20 min (15), N = 56,676	-	52 min (52), N = 44,720	*p<0.0001*
	Door-to-bed time- median (MAD), N	20 min (15), N = 56,676	-	225 min (172), N = 47,167	*p<0.0001*
	Total length of stay- median (MAD), N	3.7hr (2.9), N = 57,257	-	4.8hr (3.5), N = 46,775	*p<0.0001*
	Length of stay for - median (MAD), N:				
	Discharged	3.0 hr (2.2), N = 43,527	-	4.0 hr (2.6), N = 35,628	*p<0.0001*
	Hospitalized	7.1 hr (4.1), n = 10,353	-	9.2 hr (5.8), N = 9,109	*p<0.0001*
	Observed	11.2 hr (8.2), N = 2,565	-	20.5 hr (9.0), N = 1,715	*p<0.0001*
	Same day care	5.8 hr (3.4), N = 654	-	7.6 hr (5.7), N = 323	*p<0.0001*
	Annual ED visits	57,257 (% change = 22)	-	46,775	*p<0.0001*
	Number of ED beds	47 (% change = 21)	-	39	*p<0.0001*
	Ratio of visits to ED beds	1218 (% change = 2)	-	1199	*p<0.0001*
	Number of hospital beds	484 (% change = -3)	-	500	*p<0.0001*
	RN hr/day	398 (% change = 18)	-	328	*p<0.0001*
	*Median Absolute Deviation (MAD)				
Gupta et al.	Median patient arrival time (time of day)	8:45AM, N = 28	-	12:43PM, N = 36	*Not reported*
	Overall median delay from admission to chemotherapy (hrs)	3.2hrs, N = 28	-	6.2hrs, N = 36	*Not reported*

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Hultman et al.	OR Time in minutes – mean (SD), N Perioperative Time in minutes - mean (SD), N Length of stay in days – mean (SD), N Physician revenue/minute hospital revenue/minute	606 (SD 146), N = 46 58 (17), N = 46 5.2 (2.3), N = 46 US $7.59 US $25.11	652 (SD 196), N = 27 65 (16), N = 27 5.6 (1.9), N = 27 - -	715 (SD 168), N = 39 73 (16), N = 39 6.3 (1.6), N = 39 US $6.28 US $21.84	*p<0.01* *p<0.01* *p<0.01* *p = 0.02* *Not significant*
Khan et al.	-	-	-	-	-
McGrath et al.	Time required to obtain and record vital signs in seconds - mean Monitoring system utilization – mean (Std Err.), N: Monitored hours/patient day Monitored hours/month Frequency of vital sign measurement – mean (Std. Err), N: SpO2 Temperature Respiratory Rate Pulse rate Clinical Alarms - mean (Std. Err.), N Clinical alarms/patient day Short duration clinical alarms/patient day Long duration clinical alarms /patient day Duration of clinical alarms/patient day Clinical alarms/monitored hour Short duration clinical alarms/monitored hour Long duration clinical alarms/monitored hour Duration of clinical alarms/monitored hour Non-clinical Alarm - mean (Std. Err.): Nonclinical alarms/patient day Short duration nonclinical alarms/patient day Long duration nonclinical alarms/patient day Duration of nonclinical alarms/patient day Nonclinical alarms/monitored hour Short duration nonclinical alarms/monitored hour Long duration nonclinical alarms/monitored hour Duration of nonclinical alarms/monitored hour Patient information present in monitoring system:	128.9 [n or N not reported] (t = 7.2416, df = 159.12) 19.57 (0.18), N = 71 19053.3 (308.9), N= 71 6.7(0.026), N= 71 5.63(0.024), N= 71 5.66(0.024), N= 71 7.49(0.028), N= 71 7.07 (0.46), N= 71 5.5(0.3), N= 71 1.08(0.25), N= 71 93.79(9.78), N= 71 0.4 (0.02), N= 71 0.31(0.02), N= 71 0.06(0.01), N= 71 5.33(0.523), N= 71 29.89 (2.4), N= 71 22.63(1.81), N= 71 2.67(0.26), N= 71 1679.53 (185.69), N= 71 6.39 (0.8), N= 71 4.84(0.63), N= 71 0.57(0.14), N= 71 359.24(42.78), N= 71	- - - - - - - - - - - - - - - - - - - - - - -	178.8 17.26 (0.58), N = 71 15931.25 (342.88), N = 71 6.33(0.026), N = 71 5.81(0.025), N = 71 6.15(0.026), N = 71 6.47(0.026), N = 71 4.85 (1.11), N= 71 3.85(0.84), N= 71 0.79(0.23), N= 71 59.31(16.1), N= 71 0.32 (0.08), N= 71 0.25(0.06), N= 71 0.05(0.02), N= 71 3.89(1.1), N= 71 16.78 (2.11), N= 71 9.7(1.41), N= 71 1.45(0.26), N= 71 24357.56(1708.62), N= 71 3.7 (0.53), N= 71 2.14(0.34), N= 71 0.32(0.09), N= 71 5373.81(562.91), N= 71	*p<0.0001* ***Values for RRs*** *p<0.0001* *p<0.0001* *p<0.0001* *p=1.000* *p=0.0598* *p=0.8820* *p=0.0263* *p=0.0695* *p=0.0516* *p=0.0002* *p=0.1090* *p=0.2200* *p=0.2467* *p=0.0020* *p<0.0001* *p<0.0001* *p<0.0001* *p<0.0001* *p<0.0001* *p<0.0001* *p<0.0001* *p<0.0001*

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	Last name (%) First name (%) Room and bed (%)	678/678 (100%) 678/678 (100%) 678/678 (100%)	- - -	*551*/557 (98.92%) *188*/557 (33.75%) *319*/557 (57.2%)	*p=0.0083* *P<0.0001* *P<0.0001*
Moran et al.	Care process in hospitals with consistent submissions (patients with ISS ≥ 9): First hospital MTC, n (%)	2016/17 – 12,513 (72%) 2015/16 – 11,468 (70%) 2014/15 – 10,217 (69%) 2013/14 – 9,322 (69%)	2012/13 – 7,078 (66%) 2011/12 – 5,496 (61%)	2010/11 – 4,813 (59%) 2009/10 – 3,885 (58%) 2008/09 – 2,736 (53%)	*Not reported*
	Time to arrival, hours, median (IQR)	2016/17 – 1.7 (1.2-2.6) 2015/16 – 1.7 (1.2-2.5) 2014/15 – 1.6 (1.1-2.3) 2013/14 – 1.5 (1.1-2.3)	2012/13 – 1.3 (0.9-2) 2011/12 – 1.2 (0.8-1.8)	2010/11 – 1.2 (0.8-1.7) 2009/10 – 1.2 (0.9-1.7) 2008/09 – 1.2 (0.8-1.7)	*Not reported*
	CT at any time, n (%)	2016/17 – 13,868 (72%) 2015/16 – 12,818 (71%) 2014/15 – 11,276 (69%) 2013/14 – 9748 (66%)	2012/13 – 7371 (63%) 2011/12 – 5954 (62%)	2010/11 – 4874 (57%) 2009/10 – 3766 (54%) 2008/09 – 2690 (50%)	*Not reported*
	Time to surgery, median (IQR)	2016/17 – 22 (10.9-49) 2015/16 – 22 (11-47) 2014/15 – 21 (10-48) 2013/14 – 21 (10-48)	2012/13 – 20 (7-45) 2011/12 – 19 (6-46)	2010/11 – 18 (6-45) 2009/10 – 18 (5-46) 2008/09 – 18 (5-50)	*Not reported*
	Admitted to ICU or HDU, n (%)	2016/17 – 4595 (24%) 2015/16 – 4638 (26%) 2014/15 – 4151 (25%) 2013/14 – 3696 (25%)	2012/13 – 3101 (27%) 2011/12 – 2982 (31%)	2010/11 – 2719 (32%) 2009/10 – 2288 (33%) 2008/09 – 1656 (31%)	*Not reported*
	LOS in hospital, median (IQR)	2016/17 – 9 (5-19) 2015/16 – 9 (5-19) 2014/15 – 9 (5-19) 2013/14 – 9 (5-18)	2012/13 – 9 (5-19) 2011/12 – 9 (5-18)	2010/11 – 10 (5-19) 2009/10 – 10 (5-21) 2008/09 – 10 (5-21)	*Not reported*
	LOS in ICU/HDU, median (IQR)	2016/17 – 3 (1-8) 2015/16 – 3 (1-8) 2014/15 – 3 (1-8) 2013/14 – 3 (1-8)	2012/13 – 3 (1-9) 2011/12 – 3 (1-8)	2010/11 – 4 (2-10) 2009/10 – 4 (2-10) 2008/09 – 4 (2-10)	*Not reported*
	Care process in all hospitals: First hospital MTC, year- n/N (%)	16/17 – 16,871/41149 (41%) 15/16 – 15,694 (40%) 14/15 – 14,139 (40.6%) 13/14 – 12,588 (40%)	12/13 – 9694 (36.8%) 11/12 – 6876 (31%)	10/11 – 5572/17092 (32.6%) 09/10 – 4055 (34%) 08/09 – 2789 (32%)	*Not reported*

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	Time to arrival, median (IQR)	2016/17 – 1.8 (1.3-2.8) 2015/16 – 1.7 (1.2-2.6) 2014/15 – 1.6 (1.2-2.4) 2013/14 – 1.5 (1.1-2.2)	2012/13 – 1.4 (1-2.1) 2011/12 – 1.2 (0.8-1.8)	2010/11 – 1.2 (0.8-1.8) 2009/10 – 1.2 (0.9-1.7) 2008/09 – 1.1 (0.8-1.6)	*Not reported*
	Arrival at first hospital midnight – 8.00am, n (%)	2016/17 – 7184 (16.3%) 2015/16 – 6845 (16.2%) 2014/15 – 5972 (15.8%) 2013/14 – 5241 (15.6%)	2012/13 – 4388 (15.5%) 2011/12 – 3641 (15.7%)	2010/11 – 2894 (16.1%) 2009/10 – 2049 (16.9%) 2008/09 – 1556 (17.5%)	*Not reported*
	CT at any time, n (%)	2016/17 – 28,865 (65.5%) 2015/16 – 27,059 (63.9%) 2014/15 – 23,036 (61%) 2013/14 – 19,774 (58.8%)	2012/13 – 15,626 (55%) 2011/12 – 12,313 (53%)	2010/11 – 8984 (50%) 2009/10 – 5953 (49%) 2008/09 – 4035 (45%)	*Not reported*
	Admitted direct or transfer to MTC, n (%)	2016/17 – 19,811 (48.7%) 2015/16 – 18,747 (48%) 2014/15 – 16,837 (48.3%) 2013/14 – 15,076 (48.4%)	2012/13 – 11,803 (44.8%) 2011/12 – 8893 (40.5%)	2010/11 – 7383 (43.1%) 2009/10 – 5394 (45.7%) 2008/09 – 3879 (44.7%)	*Not reported*
	Time to surgery, median (IQR)	2016/17 – 23.3 (13.6-47.3) 2015/16 – 22.5 (13.2-45.4) 2014/15 – 22.1 (12.3-46) 2013/14 – 21.5 (11.1-45.8)	2012/13 – 20.4 (8.7-44) 2011/12 – 20.5 (8.2-45.4)	2010/11 – 19.35 (6.7-44.8) 2009/10 – 19.4 (6.4-47.2) 2008/09 – 19.9 (5.8-50.5)	*Not reported*
	Admitted to ICU or HDU, n (%)	2016/17 – 7582 (17.2%) 2015/16 – 7719 (18.2%) 2014/15 – 7024 (18.6%) 2013/14 – 6347 (18.9%)	2012/13 – 5559 (19.7%) 2011/12 – 5180 (22.3%)	2010/11 – 4266 (23.8%) 2009/10 – 3090 (25.5%) 2008/09 – 2219 (24.9%)	*Not reported*
	LOS in hospital, median (IQR)	2016/17 – 10 (5-19) 2015/16 – 10 (5-19) 2014/15 – 10 (5-19) 2013/14 – 9 (5-18)	2012/13 – 9 (5-18) 2011/12 – 9 (5-18)	2010/11 – 9 (5-19) 2009/10 – 10 (5-20) 2008/09 – 10 (5-21)	*Not reported*
	LOS in ICU/HDU, median (IQR)	2016/17 – 3 (1-7) 2015/16 – 3 (1-7) 2014/15 – 3 (1-7) 2013/14 – 3 (1-7)	2012/13 – 3 (1-8) 2011/12 – 3 (1-7)	2010/11 – 4 (2-9) 2009/10 – 4 (2-9) 2008/09 – 4 (2-9)	*Not reported*
Srinivasan et al.	Have you ever used or placed an NG tube for hydration in an infant with bronchiolitis – n/N (%)				
	Physicians – YES	90/115 (78%)	-	23/114 (20%)	*p<0.001*
	Physicians – NO	25/115 (22%)	-	91/114 (80%)	*p<0.001*
	Nurses – YES	62/97 (64%)	-	11/86 (13%)	*p<0.001*
	Nurses - NO	35/97 (36%)	-	75/86 (87%)	*p<0.001*

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	What is your preference for hydration of an infant with bronchiolitis?				
	Physicians – n/N (%):				
	IV	6/115 (5%)	-	49/114 (43%)	*p<0.001*
	NG	49/115 (43%)	-	14/114 (12%)	*p<0.001*
	Either	60/115 (52%)	-	42/114 (37%)	*p<0.001*
	Nurses – n/N (%):				
	IV	28/97 (29%)	-	43/86 (50%)	*p=0.003*
	NG	9/97 (9%)	-	10/86 (12%)	*p=0.003*
	Either	59/97 (61%)	-	30/86 (35%)	*p=0.003*
	What are your concerns about using an NG tube for hydration?				
	Physicians – n/N (%):				
	NG tube may obstruct the nasal passage	24/115 (21%)	-	47/114 (41%)	*p=0.001*
	Risk of aspiration	21/115 (18%)	-	17/114 (15%)	*p=0.59*
	Accidental placement of the NG in the airway	16/115 (14%)	-	28/114 (25%)	*p=0.05*
	Parental resistance to the NG tube	73/115 (63%)	-	79/114 (69%)	*p=0.4*
	Other	23/115 (20%)	-	21/114 (18%)	*p=0.87*
	Nurses – n/N (%):				
	NG tube may obstruct the nasal passage	38/97 (39%)	-	49/86 (57%)	*p=0.02*
	Risk of aspiration	27/97 (28%)	-	36/86 (42%)	*p=0.06*
	Accidental placement of the NG in the airway	19/97 (20%)	-	8/86 (9%)	*p=0.06*
	Parental resistance to the NG tube	41/97 (51%)	-	44/86 (51%)	*p=0.24*
	Other	32/97 (33%)	-	13/86 (15%)	*p=0.006*
	Is NG an option for hydration in our hospital bronchiolitis guideline?				
	Physicians – n/N (%):				
	Yes	91/115 (79%)	-	29/114 (25%)	*p<0.001*
	No	0/115 (0%)	-	7/114 (6%)	*p<0.001*
	Can't tell	22/115 (19%)	-	77/114 (68%)	*p<0.001*
	Nurses – n/N (%):				
	Yes	71/97 (73%)	-	24/86 (28%)	*p<0.001*
	No	0/97 (0%)	-	3/86 (3%)	*p<0.001*
	Can't tell	25/97 (26%)	-	59/86 (69%)	*p<0.001*
	Is NG an option for hydration in the AAP bronchiolitis guideline?				
	Physicians – n/N (%):				
	Yes	70/115 (61%)	-	48/114 (42%)	*p=0.002*

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	No Can't tell	2/115 (2%) 42/115 (37%)	- -	0/114 (0%) 65/114 (57%)	*p=0.002* *P=0.002*
Chandrasekar et al.	Reduction in average length of stay for AKI pre – post project	2.6hrs (14.1%), [n or N not reported]	-	-	*p<0.0001*
Kane et al.	Average hospital occupancy rate	92% [n or N not reported]	-	85% [n or N not reported]	*Not reported*
	Average in-patient length of stay for department of medicine – days	5.3 [n or N not reported]	5.5 [n or N not reported]	5.7 [n or N not reported]	*Not reported*
	Time from request for admission bed till patient departs from emergency department at 92% occupancy - hrs	6.3 [n or N not reported]	-	9.7 [n or N not reported]	*Not reported*

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Table 4b – Numbers and numerical values – Service, Resource or Cost outcomes: Studies with Concurrent Control Designs

Study	Outcomes measures	Intervention	Control 1	Control 2	Control 3	P-values
Dennerlein et al., 2017[17]	All injuries – n/N (%)	388/2131 (18.2%)	180/2414 (7.46%)	-	-	-
	Body part affected - Neck/Shoulder pain:					
	Count – n/N (%)	43/2131 (2.0%)	11/2414 (0.46%)	-	-	-
	Rate/100FTEs (95% CI)	2.0 (1.5 – 2.7)	0.46 (0.25 – 0.85)	-	-	-
	Cause of injury - Lifting/exertion injuries					
	Count – n/N (%)	174/2131 (8.1%)	48/2414 (1.99%)	-	-	-
	Rate/100FTEs (95% CI)	8.2 (7.0 – 9.5)	1.99 (1.50 – 2.64%)	-	-	-
	Nature of injury - Pain and inflammation					
	Count – n/N (%)	119/2131 (5.6%)	29/2414 (1.20%)	-	-	-
	Rate/100FTEs (95% CI)	5.6 (4.7 – 6.7)	1.20 (0.83 – 1.73)	-	-	-
Huntington et al., 2012[22]	Volume of blood supplies received (as a proxy indicator for improvements in availability of essential medical projects for maternal health services)	983 units	941 units in Camarines Sur	-	-	-
	Number of women's health teams formed	871 teams	391 teams	[Other control provinces reported no data]	-	-
	Proportion of first level referral providers who completed a clinical training programme	74%, [n or N not reported]	[No data provided by control provinces]	-	-	-
	Facility-based delivery rate by province [showing best three of five controls]	72%, [n or N not reported]	46%, [n or N not reported]	34%, [n or N not reported]	33%, [n or N not reported]	-
New et al., 2016[11]	NOTECHS Mean (SD) - a measure of operating teams' non-technical skills	77.84 (11.59), N = 25	78.06 (6.57), N = 16	-	-	*p=0.938*
	WHO Time Out attempt - Component of WHO surgical safety checklist – n/N (%)	24/25 (96%)	16/16 (100%)	-	-	*p=1.000*
	WHO Time-Out complete compliance - number of cases in which all three components of Time-Out were completed - n/N (%)	9/25 (36%)	10/16 (62%)	-	-	*p=0.621*
	WHO Sign Out - number observed- n/N (%)	1/25 (4%)	1/16 (6%)	-	-	*p=1.000*
	Glitch rate/hour - these are deviations from recognised process with potential to reduce quality or speed – mean (SD), N	6.59 (SD 3.95), N = 25	7.94 (SD 4.01), N = 16	-	-	*p=0.098*

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	Length of stay in days (SD), N	7.7 (SD 15), N = 292	7.6 (SD 16), N = 173	-	-	*p=0.396*
Rothemich et al.[12]	Counselling behaviour:					
	Ask – patient was asked if you smoke	*525*/857 (61.2%)	*637*/958 (66.5%)	-	-	*p=0.45*
	Advise- patient was advised to stop	*499*/857 (58.2%)	*530*/958 (55.3%)	-	-	*p=0.39*
	In-office cessation support(unadjusted)	*349*/857 (40.7%)	*270*/958 (28.2%)	-	-	*p<0.001*
	In-office cessation support (adjusted)	*333*/857 (38.9%)	*273*/958 (28.5%)	-	-	
	Patient who had discussion	*295*/857 (34.4%)	*262*/958 (27.4%)	-	-	*p=0.001*
	Patients who had referral to quitline	*183*/857 (21.4%)	*83*/958 (8.7%)	-	-	*p<0.001*
Rustagi et al., 2016[1]	Mean proportion of pregnant women tested for HIV at antenatal care visit:	Overall mean=95.9%, N = 18	Overall mean=93.4%, N=18	-	-	-
	Cote d'Ivoire	100%, N = 6	99.9%, N = 6	-	-	-
	Kenya	96.0%, N = 6	87.3%, N = 6	-	-	-
	Mozambique	91.7%, N = 6	92.9%, N = 6	-	-	-
Allaudeen et al.	Reduction in ED length of stay for combined medicine and surgical admissions	0.7hrs (*p-0.003*), [n or N not reported]	0.0hrs (*p=0.2*), [n or N not reported]	-	-	*p=0.001*
McGrath et al.	Frequency of vital sign measurement - mean (Std Err.), N:					
	SpO2	6.7(0.026), N = 71	6.24(0.027), N = 61	-	-	-
	Temperature	5.63(0.024), N = 71	5.57(0.026), N = 61	-	-	-
	Respiratory Rate	5.66(0.024), N = 71	5.83(0.026), N = 61	-	-	-
	Pulse rate	7.49(0.028), N = 71	7.06(0.029), N = 61	-	-	-
	System utilisation - mean (Std Err.), N:					
	Monitored hours/patient day	19.57(0.18), N = 71	12.98(0.58), N = 61	-	-	-
	Monitored hours/month	19053.3(308.9), N = 71	5225.05(208.95), N = 61	-	-	-
	Clinical Alarms - mean (Std Err.), N:					
	Clinical alarms/patient day	7.07(0.46), N = 71	5.73(0.63), N = 61	-	-	-
	Short duration clinical alarms/patient day	5.5(0.3), N = 71	4.52(0.49), N = 61	-	-	-
	Long duration clinical alarms /patient day	1.08(0.25), N = 71	1.06(0.09), N = 61	-	-	-
	Duration of clinical alarms/patient day	93.79(9.78), N = 71	73.84(9.7), N = 61	-	-	-
	Clinical alarms/monitored hour	0.4(0.02), N = 71	0.5(0.07), N = 61	-	-	-

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	Short duration clinical alarms/monitored hour	0.31(0.02), N = 71	04(0.06), N = 61	-	-	-
	Long duration clinical alarms/monitored hour	0.06(0.01), N = 71	0.09(0.01), N = 61	-	-	-
	Duration of clinical alarms/monitored hour	5.33(0.52), N = 71	6.47(1.22), N = 61	-	-	-
	Non-clinical Alarm - mean (Std Err.), N:					
	Nonclinical alarms/patient day	29.89(2.4), N = 71	26.34(6.38), N = 61	-	-	-
	Short duration nonclinical alarms/patient day	22.63(1.81), N = 71	14.32(1.9), N = 61	-	-	-
	Long duration nonclinical alarms/patient day	2.67(0.26), N = 71	1.58(0.2), N = 61	-	-	-
	Duration of nonclinical alarms/patient day	1679.53(185.69), N = 71	56084.88(15639.76), N = 61	-	-	-
	Nonclinical alarms/monitored hour	6.39(0.8), N = 71	1.0(0.4), N = 61	-	-	-
	Short duration nonclinical alarms/monitored hour	4.84(0.63), N = 71	0.54(0.15), N = 61	-	-	-
	Long duration nonclinical alarms/monitored hour	0.57(0.14), N = 71	0.06(0.02), N = 61	-	-	-
	Duration of nonclinical alarms/monitored hour	359.24(42.78), N = 71	2132.4(676.96), N = 61	-	-	-

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Table 5 – Study source, year and systems aspects

	Study	Source	Year	Country	Systems -Approach	Systems-Intervention	Design	Risk	Score
1	**Afsar-manesh et al.**[2]	Healthcare	2016	USA	1	1	0	0	2
2	**Bhatt et al.**[16]	J. of Med. Syst.	2014	USA	1	1	0	1	3
3	**Bhutani et al.**[15]	J. of Obs., Gyn. & Neo. N	2006	USA	1	1	0	1	3
4	**Bradley et al.**[14]	Int. J. of QHC	2011	Ethiopia	1	1	0	0	2
5	**Catchpole et al.**[13]	JAMA Surgery	2014	USA	1	1	1	0	3
6	**Dennerlein et al.**[17]	BMJ Occ. & Envir. Med.	2017	USA	1	1	1	0	3
7	**Hathout et al.**[19]	Leadership in Health S.	2013	Canada	1	1	1	0	3
8	**Heymann et al.**[18]	Israeli Med. Ass. J.	2004	Israel	1	1	0	0	2
9	**Huntington et al.**[22]	Bull. Of WHO	2012	Philippines	1	1	1	0	3
10	**Hwang et al.**[6]	E. J. of Emerg. Med.	2017	Korea	1	1	0	0	2
11	**Kottke et al.**[21]	The Permanente Journal	2016	USA	1	1	0	0	2
12	**Lick et al.**[8]	Critical Care Medicine	2011	USA	1	1	0	0	2
13	**Loh et al.**[5]	Int. J. of HCQA	2017	Singapore	1	1	1	1	4
14	**McKetta et al.**[7]	The Joint Co. JQ&PS	2016	USA	1	1	1	0	3
15	**New et al.**[11]	PLOS One	2016	UK	1	1	0	0	2
16	**Rateb et al.**[10]	Int. J. of HCQA	2011	Egypt	1	1	1	0	3
17	**Rothemich et al.**[12]	A. J. of Prev. Medicine	2010	USA	1	1	0	0	2
18	**Rustagi et al.**[1]	J. of AIDS	2016	Africa (3)*					
19	**Ryan et al.**[9]	Drug & Alcohol Depend.	2006	UK	1	1	0	0	2
20	**Shultz et al.**[4]	A. J. of Public Health	2015	USA	1	1	1	0	3
21	**Tetuan et al.**[3]	J. of Nursing Reg.	2017	USA	1	1	0	1	3
22	**Allaudeen et al.**	Quality Management in Health Care	2017	USA	1	1	1	0	3
23	**Anderson et al.**	The Permanente Journal	2017	USA	1	1	1	0	3
24	**Bell et al.**	BMJ Tobacco Control	2017	UK	0	1	0	0	1
25	**Bowen et al.**	J. of Digital Imaging	2016	USA	1	0	1	0	2
26	**Cochran et al.**	J. of Medical Systems	2018	USA	1	1	1	1	4
27	**DeFlitch et al.**	Health Env. Research & Design J.	2015	USA	1	1	1	1	4
28	**Gupta et al.**	J. of Oncology Practice	2018	USA	1	0	1	0	2
29	**Hultman et al.**	Annals of Plastic Surgery	2016	USA	0	1	1	0	2
30	**Khan et al.**	British Medical J.	2018	CANADA/USA	0	1	1	0	2
31	**McGrath et al.**	IEEE J. of Biomedical & Health Infor.	2019	USA	1	1	1	1	4
32	**Moran et al.**	E-Clinical Medicine	2018	UK	1	1	0	1	3
33	**Srinivasan et al.**	Hospital Pediatrics	2017	USA	1	1	1	1	4
34	**Chandrasekar et al.**	QJM: An Int. J. of Medicine	2017	UK	1	1	1	1	4
35	**Kane et al.**	Joint Com. J. Qual. & Patient Safety	2019	USA	1	1	1	0	3

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Quality assessment

Table 1: CASP questions for appraisal of a Cohort Study (possible answers for each question are Yes (Y), Can't Tell (CT), No (N))

		Studies	1. Did the study address a clearly focused issue?	2. Was the cohort recruited in an acceptable way?	3. Was the exposure accurately measured to minimise bias?	4. Was the outcome accurately measured to minimise bias?	5. (a) Have the authors identified all important confounding factors?	5. (b) Have they taken account of the confounding factors in the design and /or analysis	6. (a) Was the follow up of subjects complete enough?	6. (b) Was the follow up of subjects long enough?	7. Do you believe the results?	8. Can the results be applied to the local population?	9. Do the results of this study fit with other available evidence?	10. What are the implications of this study for practice?
1	**Cohort**	**Afsar-manesh et al.**[2]	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y	Y
2	**Case Control**	**Bhatt et al.**[16]	See	Next										
3	**Case Control**	**Bhutani et al.**[15]	See	Next										
4	**Cohort**	**Bradley et al.**[14]	Y	Y	Y	Y	CT	CT	Y	Y	Y	N	Y	Y
5	**Case Control**	**Catchpole et al.**[13]	See	Next										
6	**Cohort**	**Dennerlein et al.**[17]	Y	Y	Y	Y	CT	CT	Y	Y	Y	N	Y	Y
7	**Cohort**	**Hathout et al.**[19]	Y	Y	Y	CT	Y	CT	Y	CT	Y	Y	CT	Y
8	**Cohort**	**Heymann et al.**[18]	Y	N	CT	N	N	N	CT	CT	CT	CT	CT	N
9	**Cohort**	**Huntington et al.**[22]	Y	Y	N	Y	Y	Y	Y	CT	CT	N	Y	Y
10	**Cohort**	**Hwang et al.**[6]	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y
11	**Cohort**	**Kottke et al.**[21]	Y	Y	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y
12	**Cohort**	**Lick et al.**[8]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
13	**Cohort**	**Loh et al.**[5]	Y	Y	CT	Y	Y	Y	Y	Y	Y	N	Y	CT
14	**Cohort**	**McKetta et al.**[7]	Y	Y	Y	Y	CT	CT	Y	CT	Y	Y	Y	Y
15	**Cohort**	**New et al.**[11]	CT	Y	Y	CT	N	N	Y	N	N	CT	CT	CT
16	**Cohort**	**Rateb et al.**[10]	Y	Y	Y	Y	CT	CT	CT	CT	Y	Y	Y	Y
17	**RCT**	**Rothemich et al.**[12]	See	Two	Next									
18	**RCT**	**Rustagi et al.**[1]	See	Two	Next									
19	**Cohort**	**Ryan et al.**[9]	Y	Y	CT	CT	CT	CT	Y	Y	CT	CT	Y	Y
20	**Cohort**	**Shultz et al.**[4]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
21	**Cohort**	**Tetuan et al.**[3]	Y	Y	CT	CT	Y	CT	Y	CT	CT	Y	Y	CT
22	**Case Control**	**Allaudeen et al.**	See	Next										
23	**Cohort**	**Anderson et al.**	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y
24	**Cohort**	**Bell et al.**	Y	Y	Y	Y	Y	CT	CT	N	Y	CT	Y	Y
25	**Cohort**	**Bowen et al.**	Y	Y	Y	Y	CT	CT	N	N	Y	CT	Y	Y
26	**Cohort**	**Cochran et al.**	Y	Y	Y	Y	N	N	CT	Y	Y	CT	CT	Y
27	**Cohort**	**DeFlitch et al.**	Y	Y	Y	Y	Y	CT	CT	Y	Y	CT	Y	Y
28	**Cohort**	**Gupta et al.**	Y	Y	Y	Y	CT	CT	CT	Y	Y	Y	Y	Y
29	**Cohort**	**Hultman et al.**	Y	Y	Y	Y	Y	CT	CT	Y	Y	Y	Y	Y
30	**Cohort**	**Khan et al.**	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
31	**Case Control**	**McGrath et al.**	See	Next										

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32	**Cohort**	**Moran et al.**	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y
33	**Cohort**	**Srinivasan et al.**	Y	Y	Y	Y	Y	CT	CT	N	CT	CT	CT	CT
34	**Cohort**	**Chandrasekar et al.**	Y	Y	Y	Y	Y	CT	CT	Y	CT	CT	CT	CT
35	**Cohort**	**Kane et al.**	Y	Y	Y	Y	Y	CT	CT	CT	CT	CT	CT	CT

		Studies	1. Did the study address a clearly focused issue?	2. Did the authors use an appropriate method to answer their question?	3. Were the cases recruited in an acceptable way?	4. Were the controls selected in an acceptable way?	5. Was the exposure accurately measured to minimise bias?	6. (a) Aside from the experimental intervention were the groups treated equally?	6. (b) Have the authors taken account of the potential confounding factors in the design and/or in their analysis?	7. How precise are the results?	8. Can this be applied to the local population?	9. Do the results fir with other available evidence?
2	**Case Control**	**Bhatt et al.**[16]	Y	Y	Y	N	Y	Y	Y		Y	CT
3	**Case Control**	**Bhutani et al.**[15]	Y	Y	Y	Y	Y	Y	Y		Y	Y
5	**Case Control**	**Catchpole et al.**[13]	Y	Y	Y	Y	Y	Y	Y		Y	Y
22	**Case Control**	**Allaudeen et al.**	Y	Y	Y	Y	Y	Y	Y		CT	CT
31	**Case Control**	**McGrath et al.**	Y	Y	Y	CT	Y	CT	Y		Y	Y

		Studies	1. Did the trial address a clearly focused issue?	2. Was the assignment of patients to treatments randomised?	3. Were all the patients who entered the trial properly accounted for at its conclusion?	4. Were patients, health workers and study personnel blind to treatment?	5. Were the groups similar at the start of the trial?	6. Aside fro the experimental intervention, were the groups treated equally?	7. Can the results be applied to the local population, or in your context?	8. Were all clinically important outcomes considered?	9. Are the benefits worth the harms and risks?
	RCT	**Rothemich et al.**[12]	Y	Y	Y	N	Y	Y	Y		Y
	RCT	**Rustagi et al.**[1]	Y	Y	Y	N	Y	Y	Y		Y

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	4
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	5
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	6
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	6-8
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	6-8

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5, 8
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	-
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	5,8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	7-8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	7-8
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	-
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	9
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	10
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	11
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	11

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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BMJ Open

A systems approach to health service design, delivery and improvement: A systematic review and meta-analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-037667.R1
Article Type:	Original research
Date Submitted by the Author:	02-Oct-2020
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Primary Subject Heading:	Health services research
Secondary Subject Heading:	Health services research, Health policy
Keywords:	Organisation of health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Quality in health care < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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A systems approach to health service design, delivery and improvement: A systematic review and meta-analysis

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Key words

Systems approach, Systematic Review, Quality improvement, Healthcare design, Health systems engineering

Word count: 3,571; **Reference count**: 81

Abstract

Objectives

To systematically review the evidence-base for a systems approach to healthcare design, delivery or improvement.

Design

Systematic review with meta-analyses

Methods

Included were studies in any patients, in any healthcare setting where a systems approach was compared to usual care which reported quantitative results for any outcomes for both groups. (protocol - PROSPERO CRD42017065920). We searched Medline, Embase, HMIC, Health Business Elite, Web of Science, Scopus, PsycINFO and CINAHL from inception until 28th May 2019 for relevant studies. These were screened, and data extracted independently and in duplicate. Study outcomes were stratified by study design and whether they reported patient and/or service outcomes. Meta-analysis was conducted with Revman software version 5.3 using odds ratios - heterogeneity was assessed using I^2 statistics.

Results

Of 11,405 records 35 studies were included, of which 28 (80%) were before-and-after design only, five were both before-and-after and concurrent design, and two were RCTs. There was heterogeneity of interventions and wide variation in reported outcome types. Almost all results showed health improvement where systems approaches were used. Most studies were of before-and-after design and quality varied widely. Exploratory meta-analysis of these suggested favourable effects on both patient outcomes (n=14, OR=0.52 (95%CI 0.38 to 0.71) I^2 = 91%), and service outcomes (n=18, OR=0.40 (95%CI 0.31 to 0.52) I^2 = 97%).

Conclusions

This study suggests that a systems approaches to healthcare design and delivery results in a statistically significant improvement to both patient and service outcomes. However, better quality studies, particularly randomised controlled trials are needed.

Strengths and limitations of this study

- This is the first systematic review to provide a comprehensive and transparent synthesis of the published evidence-base for a systems approach to healthcare design, delivery and improvement.
- A major limitation of our study rests on the heterogeneity of the literature it seeks to synthesise, with wide variation in the settings, participants, comparators, follow-up durations, and study designs.
- We have conducted two exploratory meta-analyses in order to give an overview of the general direction of results, and we acknowledge that these may give artificial numerical precision which may not be warranted.
- This benefit must be interpreted and applied with care because the evidence mostly comes from before and after study designs, with inherent confounding factors of unknown magnitude and direction.
- Several included studies reported both the potential of a Hawthorne effect and the existence of other interventions at the time of their study which may have contributed to their observed outcomes.

Introduction

The 20th and 21st centuries have witnessed the development of highly effective healthcare technologies, diagnoses and interventions.[1,2] Nonetheless, there remains a pressing need for improvement in both the quality and safety of care delivery.[3–5] This is often attributed to several factors including multimorbidity,[6] the complexity of healthcare delivery,[7] and a variety of cultural and organisational challenges[8,9]. Drawing on the experience of fields such as engineering and design a "systems approach" to improvement has been advocated, that recognises the interacting components of healthcare delivery, the people involved, as well as planned, considered and adaptive iterative implementation.[10–16] However, there has not been a systematic review of the evidence-base for such an approach within the healthcare literature to date.

Modern healthcare systems are striving for integrated, patient-centred, effective, and efficient care[17] but the lesson from engineering is that such systems do not happen by accident; they need to be planned, designed, and built. [18] Understanding what this process might look like has been explored with reference to the literature on Patient Safety,[19] Human Factors and Ergonomics (HFE),[20] General Practice,[21] the wellbeing of healthcare workers[22] and Public Health.[23] These reviews, while useful, are limited in their scope and employ narrow views of a systems approach.

The primary objective of this study is to review, comprehensively, the usefulness of a systems approach to healthcare improvement. There were no limits on language, participant types, outcome types or any particular healthcare domain.

Definition of a systems approach

Defining a systems approach is challenging. The approach has origins in a variety of disciplines, which have both diverged and converged over the past century. These range from mathematics to social science, and span both the physical and biological sciences.[24] In order to arrive at a definition that we could operationalise for the purpose of this systematic review, the team reviewed definitions of a systems approach including Clarkson et al.,[10] Maier and Rechtin,[25] Chen[26] and the NASA systems engineering handbook[27]. As a result, we developed a shared understanding of a system, at its fundamental level, as:

A collection of different elements (or things) which together produce results unachievable by the individual elements on their own.[28]

Our working definition of a systems approach, which has been informed by Clarkson et al.[10], is as follows:

A systems approach to healthcare improvement is a way of addressing health delivery challenges that recognises the multiplicity of elements interacting to impact an outcome of interest and implements processes or tools in a holistic way.

This view of a systems approach integrates perspectives on people, systems, design and risk in a way that is applicable to healthcare systems across all scales from local service systems through to organisational, cross-organisational and national policy levels.

Methods

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard[29]. The complete PRISMA checklist is included in the supplementary materials.

Following a preliminary review of the Cochrane systematic review database and the PROSPERO database of ongoing reviews, we developed and registered a protocol for this systematic review (PROSPERO CRD42017065920).

Included were published primary research studies involving any patients in any healthcare setting where a systems approach was compared to concurrent or historical comparators - usual care or a non-systems approach, which reported numerical results for both groups for any outcomes relevant to the study being conducted. Excluded were conference reports or other unpublished studies, studies without clear evidence of a systems approach being used, studies without any type of comparator, or studies without quantitative outcome data for either group.

Information sources

We searched the following databases with no limits on date of publication: Medline, Embase and HMIC (via OVID), Health Business Elite, PsycINFO and CINAHL (via EBSCO), Web of Science and Scopus. The search was first conducted in August 2017 and repeated on 28th May 2019. It was repeated for a second time on 24th July 2020, but we found very little additional evidence, in particular nothing that would affect the meta-analysis direction and the conclusions of the systematic review. As a result, the analysis and results presented here are based studies up to May 2019. There were no limits on, language, participant types, outcome types or any healthcare domain. The full search strategy including specific search strings are provided in supplementary file 1.

Study selection process

We used a structured, two-stage, approach to determine inclusion. The first stage involved a title/abstract review of citations after removing duplicates. The second consisted of a full text review of the 107 papers identified as potential for inclusion.

For the title/abstract review stage, three pairs of researchers looked at a third of the records each. Studies were selected for inclusion or rejection independently by each researcher, and with differences resolved first within the pair, and then within the whole team where the pair could not agree.

The full text review stage applied the definition of a system and of a systems approach as stated above. Researcher pairs individually reviewed studies for inclusion or exclusion based on the following two questions:

1. Does the study identify a clear problem framed in a systems context and demonstrate the use of a systems approach, in some way? AND
2. Does the study have an appropriate design to address the research question?

Question one excluded any study which did not in some way demonstrate a systems approach in its formulation and/or implementation of an improvement intervention, while question two excluded all protocols, conference abstracts, systematic reviews, reviews, editorials and any paper with no primary research or no comparator arm.

Following the individual assessment, members of each pair discussed their results to arrive at a consensus on which studies to include. As a final check for all included studies, the team assessed each study against aspects of our working definition of a systems approach. Studies were assessed on a binary scale (0 or 1) as to whether they demonstrate a consideration of systems in the development of an intervention or in the implementation of the intervention, use of design and a consideration of risk. The outcome of this assessment is shown in table 1 in supplementary file 2. A full list of excluded studies with reasons for exclusion is also provided in supplementary file 3. Our method is also summarised using the PRISMA systematic review process shown in figure 1.

Data collection

A template for data extraction was developed by the research team working through samples of the selected papers to identify relevant fields and tables appropriate to the study question. The data extraction process was designed to include an element of quality control and minimisation of researcher bias. The lead author initially extracted data from all included studies using the agreed template, with other team members each assigned a subset of these to independently corroborate.

Data were extracted into five tables as listed below, and all included in supplementary file 2. Patient outcomes and service outcomes are each separated into two tables according to study design(see tables 2-5b in supplementary file 2). Tables 6-8 in supplementary file 2 are the results of applying the Critical Appraisal Skill Programme (CASP)[30] questions to included studies:

1. Study source, Country, year and aspects of systems approach
2. Characteristics of studies (population and intervention)
3. Characteristics of studies (design, baseline type, blinding, and funding source)
4. Patient outcomes
    a. Patient outcomes for studies with before and after design
    b. Patient outcomes for studies with concurrent design
5. Service outcomes
    a. Service outcomes for studies with before and after design
    b. Service outcomes for studies with concurrent design
6. CASP questions for appraisal of Cohort Studies
7. CASP questions for appraisal of Case Control Studies
8. CASP questions for appraisal of RCTs

Examples of patient outcomes include numbers of vaccinations received, numbers of medication events, and time to death. Examples of service outcomes include appointment delays, customer flows, and time to treatment received. We did not include every outcome as this was impossible. We also did not use summary outcomes as this will give undue weighting to some studies compared to others. Outcomes were selected based on their relevance to the overall objective of the respective studies.

Patient and Public Involvement (PPI)

Due to the focus of this review on synthesising evidence within the academic literature the involvement of PPI was not applicable.

Data analysis

Review manager (version 5.3, The Cochrane Library) was used for the meta-analyses using a random effects model due to the heterogeneity of participants, interventions and outcome measures. Meta-analysis was conducted for service outcomes and patient outcomes separately where the categories below had the highest number of studies. Categories were before-and-after studies, studies with

concurrent controls, and continuous versus categorical versus time-to-event data. The highest numbers of studies for both service and patient outcomes were the before-and-after studies so this category was used in both meta-analyses. Heterogeneity was assessed using the I^2 statistic, using standard thresholds. Risk of publication bias was assessed by use of a funnel plot primarily using the service outcome studies and adding the patient outcome results for studies not already in the service outcome meta-analysis.

Risk of bias for all studies was assessed by two researchers independently using Critical Appraisal Skills Programme (CASP) checklists[30]. These were chosen because they have a suite of checklists appropriate for different study designs. Differences were resolved through a consensus process. The CASP checklist for cohort studies, case control and RCTs were applied accordingly. The checklists consist of eleven or twelve questions in three sections – Study validity, study results and local value of results.

Results

Our initial search found 11,463 records published prior to August 2017 and an extended search in May 2019 found a further 3,081 records. After deduplication there were 11,405 citations including two records added from personal sources. Of these, 11,298 records were excluded after the scanning process, leaving 107 full texts. Included were 35 studies, out of which 23 provided sufficient data for the two meta-analyses conducted (Figure 1).

Of the 35 included studies, 28 (80%) had a before-and-after design only. Six studies had both a before-and-after and concurrent design (including two RCTs). Summary characteristics of included studies are presented in Table 1. Studies excluded at the full text review stage, with reasons for exclusion, are provided in the online supplementary file 3.

There was considerable diversity in how a systems approach was conceptualised and implemented in the included studies. This diversity in approaches may be categorised in three ways:

1. A comprehensive implementation of traditional tools and approaches such as PDSA, Lean, Human Factors Engineering, WHO health systems strengthening principles, SEIPS model, Business Process Re-engineering, Structure- Process- Outcome (SPO) and various combinations of these.[31–40]
2. A focus on the breadth of coverage of the intervention, involving a wide range of stakeholders from patients, communities, multiple departments including consideration of physical structures.[41–55]
3. The application of standard systems concepts such as systems thinking and complex adaptive systems theory.[56–60]

Almost all included studies showed a benefit for using a systems approach for almost all the outcomes. The exceptions were, New et al., 2016[34] (service outcome, concurrent control) and Dennerlein et al., 2017[49] (service outcome, concurrent control). Most of the factors reported as contributing to success were related to people. These were expressed in the form of engaging with stakeholders, taking a team-based approach, enhancing communication, adopting a collaborative approach, patient-centeredness and physician-centeredness. Similarly, difficulty in measuring impact and the inability to generalise to other contexts emerged as the most significant limitations.

We included two RCTs in our systematic review. Both reported significant improvements in outcomes favouring a systems approach. Rustagi et al.[36] randomised 36 health facilities in Cote d'Ivoire, Kenya and Mozambique to usual care or "a systems engineering intervention" stratified by country and volume. They found that antiretroviral (ARV) coverage for HIV positive women increased 3-fold in

intervention facilities compared to control facilities whilst HIV-Exposed Infants (HEI) screening increased 17-fold. Similarly, Rothemich et al.[54] randomised 16 practices into intervention (8) and control (8) groups to determine whether a systems approach enhances smoking cessation support in primary care practices. The study concluded that a systems approach to identifying smokers, advising, assessing readiness to quit and referral to supporting agencies, led to statistically significant increases in cessation for patients irrespective of gender, compared to traditional tobacco-use vital sign screening alone.

Table 1: Characteristics of included studies

Study	Country	Health setting	Population	Intervention	Study type	Follow up duration	Participants		Outcomes
							Before	After	
Afsar-manesh et al., 2016[31]	USA	Whole hospital - in General Medicine, General Surgery, Neurosurgery, Paediatrics, Orthopaedics	Staff and patients	Comprehensive Lean methodology	Before & After	18 months	NR	NR	Patient
Allaudeen et al., 2017[37]	USA	University-affiliated department of veterans' affairs medical centre	Emergency Department patients and staff	Lean-based multi-disciplinary initiative and PDSA	Before & After/ Concurrent control	3 years	NR	NR	Service
Anderson et al., 2017[43]	USA	The University of Colorado hospital academic medical centre	Geriatrics patients and staff	"Step-wise framework for implementing a comprehensive geriatrics hip fracture program" involving twelve steps	Before & After	17 months	154	117	Patient /Service
Bell et al., 2017[44]	UK	Eight acute NHS hospital trusts and 12 local authority areas in North East England	Pregnant women	"BabyClear" – a complex intervention comprising a package of measures designed to support implementation of national guidance	Before & After	4 months	NR	NR	Patient/Service
Bhatt et al., 2014[41]	USA	Academic Medical Centre	Nursing staff	ACGME Core Competency of Systems-based Practice	Before & After	17 days	13	17	Service
Bhutani et al., 2006[42]	USA	Semi-private urban birthing hospital	Babies discharged as healthy patients' parents, paediatricians, paediatric nurses, home care nurse agencies	Systems approach to Clinical Condition Management	Before & After	12 months	3,227 8,186	8,186 11,995	Patient Service
Bowen et al., 2016[45]	USA	Grady Memorial Hospital - Single centre, hospital, stroke centre	Stroke patients	Multi-stakeholder process mapping to inform problem identification involving value stream mapping	Before & After	32 days	75	88	Service
Bradley et al., 2011[48]	Ethiopia	Primary care in Rural Ethiopia	Primary care patients	The Ethiopian Millennium Rural Initiative	Before & After	18 months	140	140	Service
Catchpole et al., 2014[32]	USA	Nonprofit, academic tertiary care medical centre	Trauma patients	A multi-disciplinary systems analysis informed by Human Factors Engineering, Systems Engineering Initiative for Patient Safety (SEIPS) and PDSA (iterative)	Before & After	5 months	14 72	13 107	Service
Chandrasekar et al., 2017[40]	UK	A university hospital in the UK	All medical inpatients at a single UK hospital	'QI Methodology' including driver diagrams, pareto charts and statistical process analysis Also includes a range of interventions involving risk assessment tools, early identification using automated alerts, development of an intervention bundle, formation of an outreach support team staff engagement and patient and family empowerment.	Before & After	34 months	NR	NR	Patient/Service

Cochran et al., 2018[38]	USA	Franciscan Health Indianapolis – a general medical and surgical centre	Patients, nurses and a team of ER and system engineering specialists	Collective System Design (CSD) methodology involving PDCA – a systems engineering methodology, which recognises systems as the amalgamation of four key elements: Work/Actions, Structure, Thinking and Tone.	Before & After	8 months	NR	NR	Patient/Service
DeFlitch et al., 2015[39]	USA	A suburban, tertiary care, academic ED, with paediatric and adult level 1 trauma	Patients and staff	"Engineering techniques" including defining a study team, process mapping, Discrete Event Simulation modelling and detailed design considerations leading to the Physician directed Queuing (PDQ) model.	Before & After	3 years	NR	NR	Patient/ Service
Dennerlein et al., 2017[49]	USA	Hospital-wide -at 2 hospitals	Direct patient care workers	A broad stakeholder engagement, new lifting equipment across hospital, new processes and group training and one-to-one coaching and mentoring for staff	Before & After	12 months	2149 2348	2131 2414	Service
Gupta et al., 2018[61]	USA	Parkland health and hospital system – a large public hospital in the USA	Healthcare staff and patients	A multi-disciplinary team delivering PDSA including process mapping	Before & After	6 months	36	28	Service
Hathout et al., 2013[50]	Canada	Province-wide, Manitoba, Canada	Healthcare staff	Stakeholder engagement, problem exploration, process mapping, exploration of systems drivers and value and objectives of services	Before & After	18 months	NR	NR	Patient/ Service
Heymann et al., 2004[51]	Israel	Maccabi Healthcare services, a Health Maintenance Organisation (HMO) serving 1.5M patients	Healthcare staff	Previously developed Systematic Inventive Thinking (SIT). Bases on "Creativity as an exact Science"	Before & After	14 months	1000	1000	Service
Hultman et al., 2016[62]	USA	Academic medical centre of the University of North Carolina Hospitals	Healthcare staff and patients	Lean-Six Sigma – using standard DMAIC model	Before & After	24 months	39 (27)	46	Patient/ Service
Huntington et al., 2012[63]	Philippines	Health systems reform in a province in the Philippines involving two tertiary hospitals, 20 first level referral health facilities. Twelve rural health units. One village health station	Women's health teams	National initiative - National Safe Motherhood Programme. Seems influenced by WHO health systems strengthening principles	Before & After/Concurrent control	4 years	16,535 NR	15,789 NR	Patient Service
Hwang et al., 2017[64]	South Korea	Multiple institutions in the chain of survival of cardiac arrest patients – community to hospital	Cardiac patients	System-wide CPR programme for OHCA patients developed by lead Hospital.	Before & After	12 months	182 282	282 182	Patient Service
Kane et al., 2019[60]	USA	A tertiary care hospital in Baltimore, USA	Nursing bed managers, transfer line operators, patient pathway coordinators	"A systems engineering approach" involving a steering group consisting of hospital CEO, CIO, COO, VP for medical affairs, Director of nursing, and project leaders. Involved working with external supplies and use of DES and ABS.	Before & After	Can't tell	NR	NR	Service

Khan et al., 2018[46]	Canada/USA	Paediatric inpatient units in seven North American hospitals in USA and Canada	Patients, parents or caregivers, nurses, medical students and residents	Co-production of intervention to standardise the structure of healthcare provider-family communication on family centred rounds.	Before & After	3 months	947 1574	890 1532	Patient
Kottke et al., 2016.[56]	USA	Private, five-clinic primary care practice	CHD patients	Complex Adaptive Systems principles	Before & After	6 months	529 529	511 511	Patient Service
Lick et al., 2011.[53]	USA	Community-based centres of excellence	Cardiac arrest patients	"Take heart America programme": Community-based initiative	Before & After	6 months	247 247	106 106	Patient Service
Loh et al., 2017[65]	Singapore	National tertiary specialist hospital	Cataract surgery patients	Systems Engineering Initiative for Patient Safety (SEIPS) Model and PDSA	Before & After	6 months	6,111	39,390	Service
McGrath et al., 2019[59]	USA	US Academic Health Centre	Patients and staff including nurses, nurse assistants, occupational therapists, physical therapists, physicians	System-level design and analysis involving system design and validation, installation and education, operation and performance measurement	Before & After/Concurrent control	5 months	557	678	Service
McKetta et al., 2016[57]	USA	The Cardiac Centre at a Children's Hospital	Cardiac centre staff	A Discrete Event Simulation together with traditional QI involving a multidisciplinary team using a four-step framework – Define, Diagnose, Test and Implement, and Sustain. Including PDSA	Before & After	4 months	135	138	Service
Moran et al., 2018[47]	UK	UK NHS in England and North Wales	Population of England and wales	Trauma systems – Systematic trauma care on a national basis.	Before & After	4years	44059 41149	17956 17092	Patient Service
New et al., 2016[34]	UK	The Orthopaedic trauma theatre of a UK hospital Trust	Theatre staff	A two-step intervention – one-day Lean training followed by 6 months coaching. Training covered Lean principles Muda, Poka-Yoke, Genchi Genbutsu, Kaizen, flow, JIT, respect and teamwork, process mapping, PDCA cycles	Before & After/Concurrent control	6 months	450 25	567 17	Patient Service
Rateb et al., 2011[66]	Egypt	Egypt HIO / community, Medical fitness testing.	HIO doctors, nurses, admin staff, customers	Business Process Re-engineering focusing on Structure, Process and Outcome. Systems approach appears to mean everything from building renovation to customer and staff satisfaction.	Before & After	Can't tell	251 101	251 101	Patient Service
Rothemich et al., 2010[67]	USA	16 primary care practices	Adult smokers, family physicians,	Called QuitLink Intervention. Limited details provided. Described as using paper-based, systems approach to identify smokers, provide advice to quit, and assess willingness to quit. Includes supporting willing smokers too access quitlines and communicate feedback from quitline to clinicians	Concurrent control (RCT)	1 month	958	857	Service
Rustagi et al., 2016[36]	Ivory Coast, Kenya and Mozambique	Mother-to-child HIV transmission prevention services in three countries in Africa – Cote d'Ivoire, Kenya and Mozambique	Healthcare staff and patients	The Systems Analysis and Improvement Approach (SAIA) – a 5-step, iterative package of systems analysis and improvement tools developed using multiple systems engineering	Before & After/Concurrent control (RCT)	9 months	17	18	Patient

				techniques including continuous quality improvement.					
Ryan et al., 2006.[55]	UK	Manchester Alcohol Service (MAS) In-patient detoxification service	Detox service users	A whole systems approach to alcohol services – A collaborative working between multiple organisations	Before & After	Can't tell	171	2,754	Patient
Shultz et al., 2015[68]	USA	5 Family Medicine Clinics and 4 Internal Medicine Clinics (as control)	Physicians and staff	Sequential and linked PDSA/Adjust cycles. A consensus-based framework that addresses the process of care	Before & After/Concurrent control	2 years	67,914	67,914	Service
Srinivasan et al., 2017[69]	USA	Emergency department and inpatient unit of a 280-bed tertiary care, free-standing children's hospital	1 - 23-month-old babies and parents	Driver Diagram plus three cycles of PDSA involving stakeholder surveys focusing on changing clinician behaviour through both education, re-enforcement and encouragement.	Before & After	3 weeks	221 114 86	91 115 97	Patient/ Service
Tetuan et al., 2017[58]	USA	Integrated health care systems comprising primary and speciality clinics, and a 568-bed acute care hospital.	Nurses	Systems Thinking Education Programme (STEP)	Before & After	12 months	1652	1998	Service

Two exploratory meta-analyses were conducted on categorical outcomes reported in before-and-after studies; one on patient outcomes (Figure 2), and one on service and resource use outcomes (Figure 3).

Exploratory meta-analysis suggests that a systems approach significantly improves both patient outcomes (n=14, OR=0.52 (95%CI 0.38 to 0.71) I^2 = 91%), and service outcomes (n=18, OR=0.40 (95%CI 0.31 to 0.52) I^2 = 97%).

Heterogeneity was very high. The funnel plot (Figure 4) is unclear regarding publication bias. If anything, it might suggest that small studies with very positive results are missing, rather than those with null results.

It is important that the above results are interpreted with the heterogeneity and the quality of the included studies in mind. The two included RCTs both had reasonably high quality. The five cohort studies with concurrent controls varied between good and fair quality. The before-and-after studies which made up 80% of included studies varied widely in quality, ranging from good to very poor. Details of the quality assessment results are included in the last three tables in supplementary file 2.

Discussion

Our novel systematic review with exploratory meta-analyses suggests that the use of a systems approach to improving care results in significant benefits for both patient and service outcomes. There were two RCTs included that individually found statistically significant improvements in outcomes associated with the use of a systems approach. These findings, together with the observation that the majority of studies had a before-and-after design present a challenge in interpretation of results in relation to what is usually considered good quality evidence. In addition, we observed a number of factors, which may support success in the use of a systems approach as reported by the included studies. To our knowledge, this is the first systematic review that has endeavoured to conduct a comprehensive synthesis of the evidence-base for a systems approach to healthcare improvement.

This review adds to a growing number of systematic reviews apparently motivated by the desire to find evidence for what works in healthcare improvement. Narrative reviews[19–23] of a systems approach in healthcare have focused on specific health issues such as patient safety, human factors and ergonomics in healthcare, primary care, wellbeing of health workers and public health. Though these generally demonstrate value of a systems approach, they lack a rigorous and comprehensive assessment of the evidence-base for this. Other systematic reviews have been conducted on most of the major healthcare improvement methodologies including Lean[70], Six Sigma,[70,71] Plan-do-Study-Act (PDSA),[72] Statistical Process Control (SPC)[73] and Quality Improvement Collaboratives (QIC),[74] with mixed results. DelliFraine et al.[70] in their review of both the Lean and Six Sigma methodologies concluded that there is very weak evidence that either of the methods improves care. However, the review did not provide a meta-analysis of the studies identified and only focused on studies between 1999 and 2009, thus limiting its value. Taylor et al.[75] in their review of PDSA found poor compliance with the original principles of the methodology but did not aim to assess the impact of the method on outcomes. In the review of SPC, the authors found considerable benefits of using the approach to monitor and control health processes, though they acknowledge some limitations exist. Wells et al.[74] in their review of QICs reported significant improvements in process and patient outcomes. Their review reported outcome measures from included studies but stopped short of a full meta-analysis. Our findings are also consistent with the expectations of positive impact from the several publications that have called for a systems approach to tackling the challenges of modern health delivery systems.[10–16] There is, clearly, considerable interest in assessing the evidence-base of various

improvement methodologies, however, existing systematic reviews have not been comprehensive enough and lack focus on patient and service outcomes.

Though the current review focuses on a systems approach to improvement, we believe this represents the most comprehensive systematic review and meta-analysis so far for evidencing the effectiveness of an improvement methodology. This is because we had no limits on date of publication, health setting, study type or participant types. We wanted the results to be relevant to a wide range of healthcare improvements contexts. However, one may object to our decision to combine very heterogenous studies as we have done because of the differences in clinical settings and outcomes being measured. We reasoned that the results of a combined study would be more useful to the healthcare community, practitioners and policy makers than an issue-specific systematic review. Moreover, several of those already exist, although not as rigorous. The inclusion of two RCTs in this review further strengthens the results. Though limited in number, both RCTs report statistically significant improvements in outcomes following the implementation of a systems approach.

Limitations

The major limitation of our study rests on the heterogeneity of the literature it seeks to synthesise, with wide variation in the settings, participants, comparators, follow-up durations, and study designs. We have sought to mitigate this using a clearly articulated definition of a systems approach, and a structured, rigorous, approach to synthesising the available evidence. We have conducted just two meta-analyses in order to give an overview of the general direction of results. We acknowledge that the estimated effect size gives an artificial precision which may not be warranted. The heterogeneity of meta-analysis results is to be expected, given the wide variation in participants, settings, interventions, comparators and outcomes. This exploratory meta-analysis can only indicate that a systems approach appears to be beneficial. This benefit must be interpreted and applied with care because the evidence mostly comes from before and after study designs, with inherent confounding factors of unknown magnitude and direction. There is also a significant risk of publication bias, and several included studies also reported both the potential of a Hawthorne effect and the existence of other interventions at the time of their study which may have contributed to their observed outcomes. The fact that we selected outcomes based on their relevance to the overall objectives of the studies included may introduce another level of bias if authors framed their objectives based on what they wanted to publish.

Implications for further research

The engineering sector is one that has excelled in the application of a systems approach[18]. The experience of the Systems Engineering community is that the value of a systems approach – in terms of quality of the resulting system, reduction in cost, delivery on time, customer satisfaction – corresponds to the extent to which a project or organisation commits to the approach.[76,77] This has implication for our findings in this review. It helps raise a number of questions that present opportunities for future research. For example, what are the different ways in which a systems approach is implemented in healthcare? Is there an association between the time and resource invested in a systems approach and the impact on patient and service outcomes? If so, what is the optimum level of investment?

Another opportunity for future research is a comparative review which assesses the impact of all improvement initiatives against those explicitly adopting a systems approach if more certainty of the value of the approach is desired. Given the volume of literature involved in such a comparative review, this would represent a significant undertaking. Studies are also needed that adopt better study designs

such as RCTs or, if necessary, develop alternative ways of understanding and achieving sufficiently robust evidence for a systems approach to healthcare design and delivery. This is a point pertinent to all improvement efforts, where the traditional medical model of the randomised controlled trial is rarely appropriate, but the need to generate convincing evidence remains pressing.

Policy implications

We have argued from the start that there has been a growing recognition of the potential value of a systems approach to healthcare improvement over the past two decades. Most of this recognition has been at the policy level, involving the World Health Organisation (WHO),[78] the Institute of Medicine (IOM) in the USA,[3,4,12] the Department of Health in the UK[79,80] and more recently, through a joint initiative between the Royal Academy of Engineering (RAEng), Royal College of Physicians (RCP) and the Academy of Medical Sciences (AMS).[10] However, to support further research and increased practice of a systems approach in health and care, policy makers need to understand the evidence-base. Though several success stories and domain-specific reviews exist, a comprehensive review of the evidence across the healthcare literature has been lacking. Our review may, therefore, become invaluable to policy-makers who have found the argument for a systems approach conceptually appealing but also desire to see the evidence of what difference such an approach can make to patient and service outcomes. In addition, the references taken individually may serve as examples of real-world application of a systems approach to healthcare improvement.

Conclusions

In summary, we have argued that a systems approach to healthcare has been championed increasingly in the health and care literature and in a variety of grey-literature reports and position documents. We provide the first attempt to, comprehensively, explore the evidence-base through a systematic review and meta-analysis. The results provide reasonably clear evidence that a systems approach to addressing health delivery challenges may lead to significant improvements in both patient and service outcomes.

Contributors

AK, TD and JW conceived the idea for the study. All authors were involved in discussions that informed the design of the study and development of the search strategy. IK conducted the database search and sourced full texts of included studies. AK, TB, JW, TD, GKK and YL did the record scanning. The full text review was done by AK, TB, JW, TD, GKK, YL, AG, JM and EO. Data extraction was undertaken by AK, TB, JW, TD, GKK, YL, AG, JM and KK. The meta-analysis and interpretation were done by CM and initial results discussed by all authors. Qualitative synthesis of included studies was conducted by AG, AK and NB whilst quality of studies were appraised by KK, AG, AK, GKK, YL, TB, JW and JM. Manuscript writing was led by AK, TB, CM, AG, PJC, JD, EO with contributions from all authors. Final approval of manuscript has been obtained from all authors. AK is the guarantor of this study.

Funding

This research was supported by the National Institute for Health Research (NIHR) Global Health Research Group on Neurotrauma using UK aid from the UK Government and the Health Foundation funded THIS Institute (The Healthcare Improvement Studies Institute) through a Postdoctoral Interdisciplinary Fellowship for AK. The views expressed in this publication are those of the authors and not necessarily those of the NIHR, the Department of Health and Social Care, the Health Foundation or THIS Institute.

Competing interests

Dr Komashie reports grants funding from The Healthcare Improvement Studies (THIS) Institute and the NIHR Global Health Research Group on Neurotrauma. Dr Ward reports grants from National Institute for Health Research and the University of Cambridge, during the conduct of the study. Dr Bashford reports grants from NIHR Global Health Research Group on Neurotrauma, during the conduct of the study. Dr Dickerson reports grants from NIHR CLAHRC East of England, during the conduct of the study. All other authors declare no competing interests.

Ethical approval

Not required

Data sharing statement

All data extracted from the included studies are included in the article or uploaded as supplementary files.

Transparency statement

The manuscripts guarantor, Dr Komashie, affirms that the manuscript is an honest, secure, accurate and transparent account of the study being reported; and that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Supplementary files

Supplementary file 1: Full search strategy – pdf.
Supplementary file 2: Data extracted from included studies – pdf.
Supplementary file 3: List of studies excluded after full text review with reasons – pdf

Acknowledgments

The authors acknowledge the help of the following bodies who provided financial support for members of the study team during the course of this work: the UK National Institute for Health Research Global Health Research Group on Neurotrauma (NIHR GHRGN), University of Cambridge, the UK National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care for the East of England (CLAHRC EoE), The Healthcare Improvement Studies (THIS) Institute. Our sincere thanks also go to Dr Nathan Crilly at the University of Cambridge Engineering Department, and Dr Guillaume Lamé of CentraleSupélec, Paris, for their constructive review of versions of the manuscript and finally to Paul Driver of Anglia Ruskin University, Cambridge for help with improving the quality of our images.

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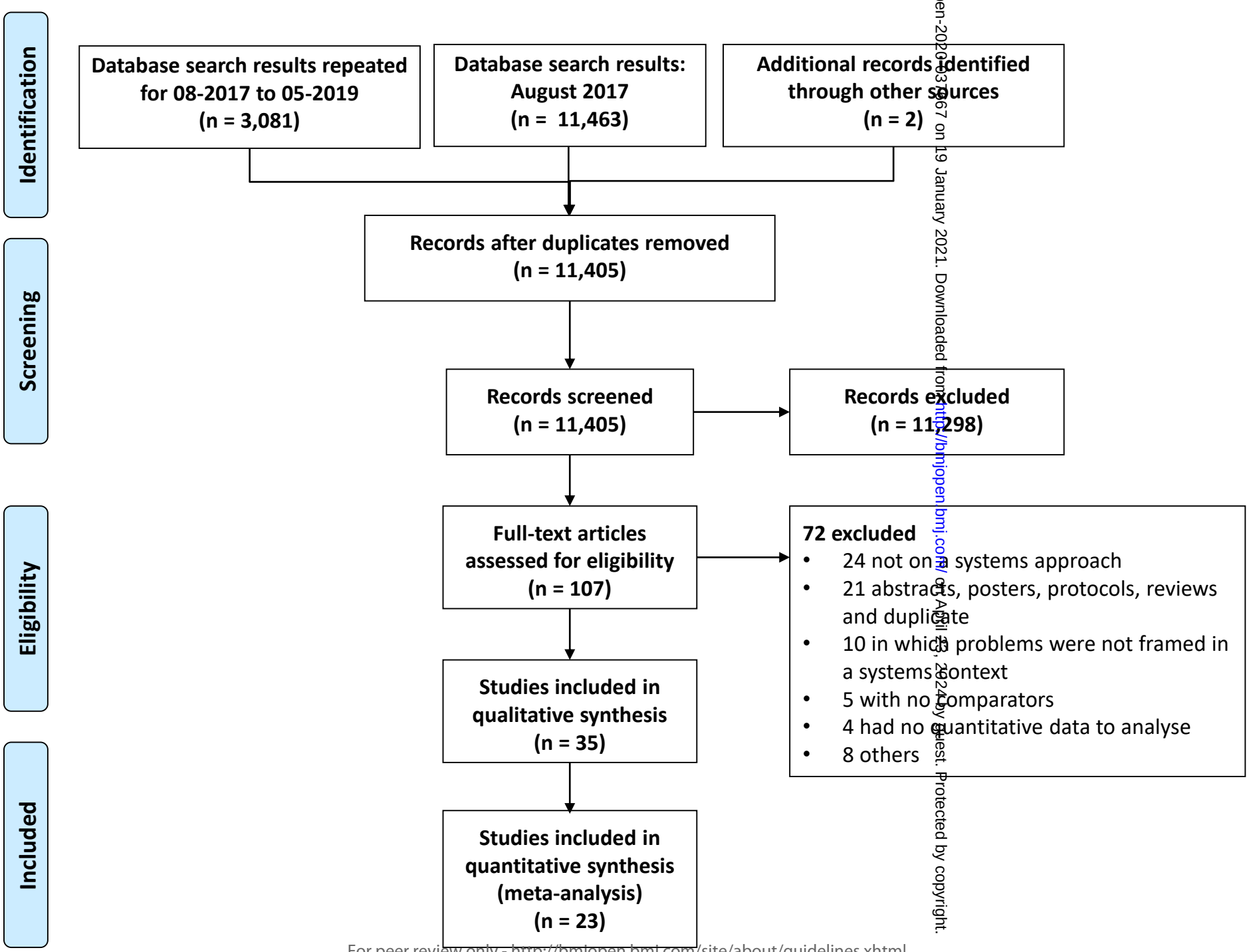
Figure captions

Figure 1: PRISMA systematic review process

Figure 2: The impact of a systems approach on patient outcomes – before and after studies

Figure 3: The impact of a systems approach on service and resource use – before and after studies

Figure 4: Funnel plot using combined service and patient outcome results



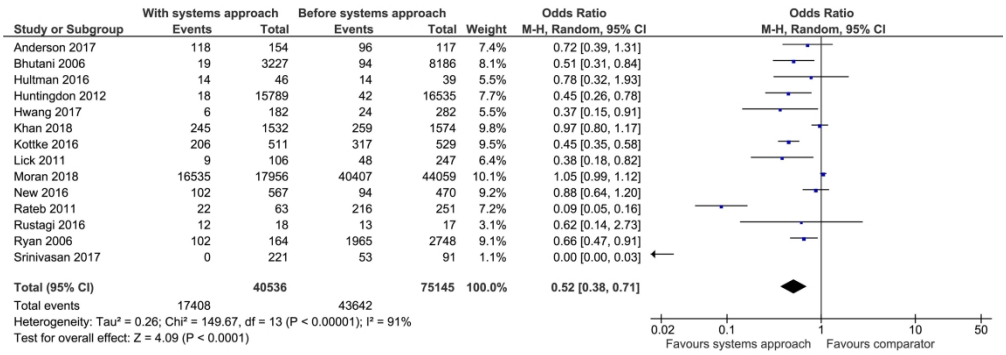


Figure 2: The impact of a systems approach on patient outcomes – before and after studies

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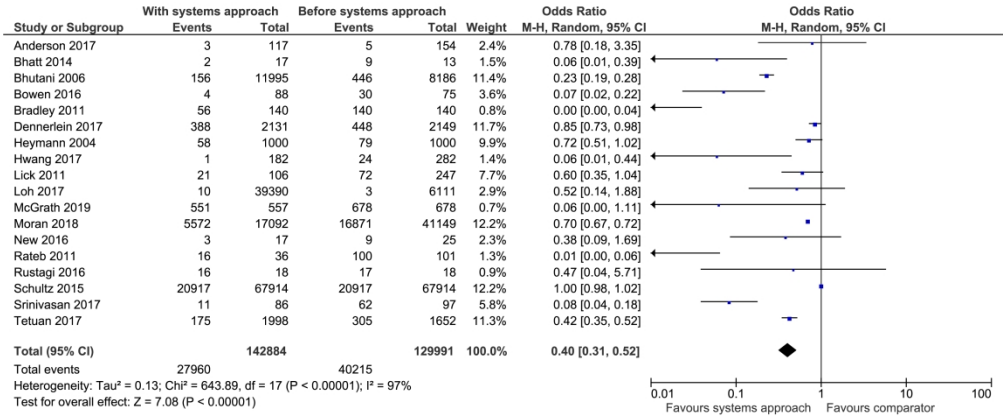

Figure 3: The impact of a systems approach on service and resource use – before and after studies

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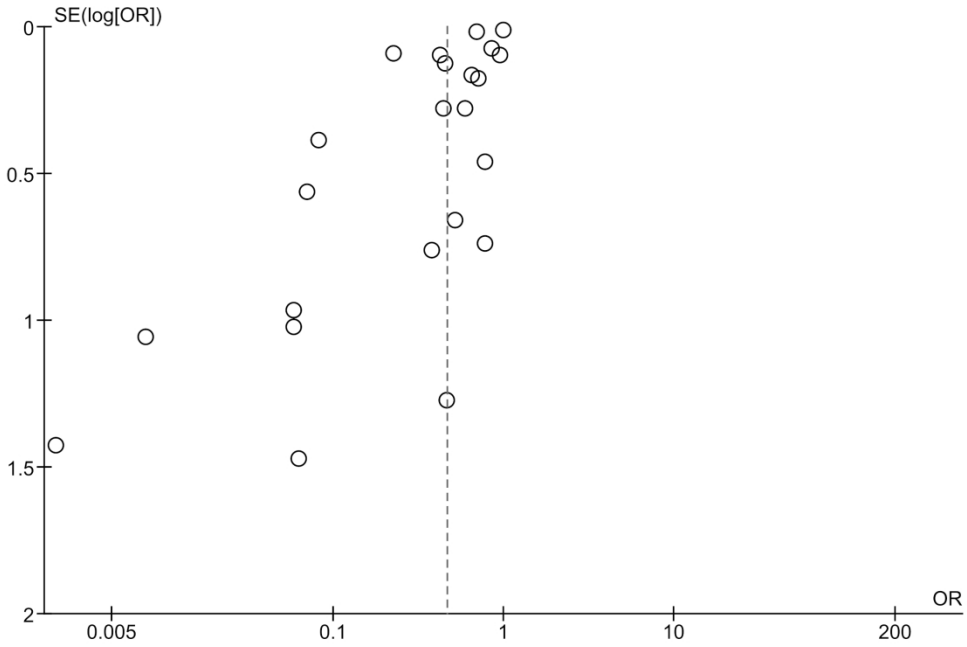

Figure 4: Funnel plot using combined service and patient outcome results

211x141mm (300 x 300 DPI)

Supplementary file 1: Full search strategy

Overview for Systematic Review: Systems Approach to Healthcare Design

Database	No. of hits: 10th Aug. 2017	No. of hits: 10th Aug. 2017 – 28th May 2019	No. of hits: 28th May 2019 – 24th Jul. 2020
Medline via OVID	1893	678	487
Embase via OVID	1351	347	295
HMIC via OVID	90	3	2
Health Business Elite via Ebsco	33	n/a	n/a
Web of Science	391	137	113
Scopus	7350	1795	1423
PsycINFO via Ebsco	86	2	3
CINAHL via Ebsco	269	119	72
Total	11,463	3081	2395
Total Deduplicated	8,834	2569	2025

Searches run 10th August 2017, 28th May 2019, 24th July 2020.

Medline

1. (((System or systems or systems-based) adj (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)).ti,ab. or exp Systems Analysis/ or exp systems theory/
2. (healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety adj3 patient*) or treatment outcome* or mortality or morbidity or (Health* adj3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))).ti,ab.
3. (design* or concept* or creat* or plan* or devis* or draft* or propos*).ti,ab.
4. (trial* or longitudinal* or (before adj3 after) or interrupted time series or control* or ((systematic* or literature*) adj review*) or meta-analys* or metaanalys* or (case adj (study* or control*))).mp.

5 1 and 2 and 3 and 4

6 ((201905* or 201906* or 201907* or 201908* or 201909* or 201910* or 201911* or 201912* 2019* or 2020*).dp. or (201905* or 201906* or 201907* or 201908* or 201909* or 201910* or 201911* or 201912* 2019* or 2020*).ez. or (201905* or 201906* or 201907* or 201908* or 201909* or 201910* or 201911* or 201912* or 2020*).ed.)

7 5 and 6

Embase

1. (((System or systems or systems-based) adj (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys*

Supplementary file 1: Full search strategy

or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)).ti,ab. or exp *Systems Analysis/ or exp *systems theory/
2. (healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety adj3 patient*) or treatment outcome* or mortality or morbidity or (Health* adj3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))).ti,ab.
3. (design* or concept* or creat* or plan* or devis* or draft* or propos*).ti,ab.
4. (trial* or longitudinal* or (before adj3 after) or interrupted time series or control* or ((systematic* or literature*) adj review*) or meta-analys* or metaanalys* or (case adj (study* or control*))).mp.

5 1 and 2 and 3 and 4

6 ((201905* or 201906* or 201907* or 201908* or 201909* or 201910* or 201911* or 201912* 2019* or 2020*).dc. or (201905* or 201906* or 201907* or 201908* or 201909* or 201910* or 201911* or 201912* or 2020*).dd)

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Web of Science

TS=((System* N1 approach*) or (system* N1 engineering) or (system* N1 science) or (system* N1 methodology*) or (system* N1 thinking) or (system* N1 dynamic*) or (system* N1 model*) or (system* N1 whole) or (system* N1 complex*) or (system* N1 ergonomics) or (system* N1 analys*) or (system* N1 theor*) or (discrete event simulation) or (sociotechnical) or (socio-technical))

AND

TS=(healthcare or (health care) or Medic* or (Health* service*) or care or nurs* or (safety N3 patient*) or (treatment outcome*) or mortality or morbidity or (Health* N3 quality) or (health* N3 safety) or (Health N3 efficien*) or (health N3 efficac*) or (health N3 performance*) or (health N3 outcome*) or (health N3 deliver*) or (health N3 experience))

AND

TS=(design* or concept* or creat* or plan* or devis* or draft* or propos*)

AND

TS=(trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review*) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*))

AND

#4 AND #3 AND #2 AND #1
Refined by: PUBLICATION YEARS: (2019 OR 2020)

CINAHL

Supplementary file 1: Full search strategy

#	Query
S7	S3 AND S4 AND S5 AND S6 Limiters - Published Date: 20190501-20201231
S6	trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*)
S5	TI (design* or concept* or creat* or plan* or devis* or draft* or propos*) OR AB (design* or concept* or creat* or plan* or devis* or draft* or propos*)
S4	TI ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience)))) OR AB ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))))
S3	S1 OR S2
S2	TI (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)) OR AU (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical))
S1	(MH "Systems Theory+") OR (MH "Systems Analysis+")

PsycINFO

#	Query
	Limiters - Published Date: 20190501-20201231
S7	S3 AND S4 AND S5 AND S6
S6	trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*)

Supplementary file 1: Full search strategy

S5	TI (design* or concept* or creat* or plan* or devis* or draft* or propos*) OR AB (design* or concept* or creat* or plan* or devis* or draft* or propos*)
S4	TI ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience)))) OR AB ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))))
S3	S1 OR S2
S2	TI (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)) OR AU (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical))
S1	(DE "Systems Theory" OR DE "Systems Neuroscience") OR (DE "Systems Analysis")

HMIC – Health Management Information Consortium

1. (((System or systems or systems-based) adj (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)).ti,ab. or exp Systems Analysis/ or exp systems theory/
2. (healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety adj3 patient*) or treatment outcome* or mortality or morbidity or (Health* adj3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))).ti,ab.
3. (design* or concept* or creat* or plan* or devis* or draft* or propos*).ti,ab.
4. (trial* or longitudinal* or (before adj3 after) or interrupted time series or control* or ((systematic* or literature*) adj review*) or meta-analys* or metaanalys* or (case adj (study* or control*))).mp.

5 1 and 2 and 3 and 4

6 ((201905* or 201906* or 201907* or 201908* or 201909* or 201910* or 201911* or 201912* 2019* or 2020*).yr. or (201905* or 201906* or 201907* or 201908* or 201909* or 201910* or 201911* or 201912* or 2020*).dp.)

7 5 and 6

Health Business Elite this database is no longer available

#	Query
S7	S3 AND S4 AND S5 AND S6

Supplementary file 1: Full search strategy

S6	trial* or longitudinal* or (before N3 after) or (interrupted time series) or control* or (systematic* review) or (literature review*) or meta-analys* or metaanalys* or (case study*) or (case control*)
S5	TI (design* or concept* or creat* or plan* or devis* or draft* or propos*) OR AB (design* or concept* or creat* or plan* or devis* or draft* or propos*)
S4	TI ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience)))) OR AB ((healthcare or (health adj care) or Medic* or (Health* adj service*) or care or nurs* or (safety N3 patient*) or treatment outcome* or mortality or morbidity or (Health* N3 (quality or safety or efficien* or efficac* or performance* or outcome* or deliver* or experience))))
S3	S1 OR S2
S2	TI (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical)) OR AU (((System or systems or systems-based) N (approach* or engineering or science or methodolog* or thinking or dynamic* or model* or Whole* or complex* or ergonomics or analys* or theor*)) or (Discrete event simulation) or (sociotechnical or socio-technical))
S1	(DE "SYSTEMS theory" OR DE "ASYMPTOTIC theory of system theory" OR DE "AUTOPOIESIS" OR DE "BIOLOGICAL systems" OR DE "CHAOS theory" OR DE "CONSTRUCTAL theory" OR DE "CYBERNETICS" OR DE "CYBERNETICS -- Social aspects" OR DE "DISCRETE systems" OR DE "EARTH system science" OR DE "LINEAR systems" OR DE "NONLINEAR systems" OR DE "OPEN systems theory" OR DE "OPERATIONS research" OR DE "SOCIAL dynamics" OR DE "SOCIAL systems" OR DE "SYNERGETICS" OR DE "SYSTEM analysis" OR DE "SYSTEMS engineering") OR (DE "SYSTEM analysis" OR DE "BEHAVIORAL systems analysis" OR DE "BOND graphs" OR DE "BUSINESS requirements analysis" OR DE "CONTROL theory (Mathematics)" OR DE "COUPLED problems (Complex systems)" OR DE "DECOMPOSITION method (Mathematics)" OR DE "DISCRETE-time systems" OR DE "DISTRIBUTED parameter systems" OR DE "ELECTRIC networks" OR DE "FLOW charts" OR DE "FLOWGRAPHS" OR DE "FUZZY systems" OR DE "HIPO technique" OR DE "INFORMATION modeling" OR DE "LARGE scale systems" OR DE "MAPS design technology" OR DE "MEMORYLESS systems" OR DE "SADT (System analysis)" OR DE "SAMPLE path analysis" OR DE "SMALL scale system" OR DE "SPATIAL systems" OR DE "STATE-space methods" OR DE "STOCHASTIC systems" OR DE "STRUCTURED techniques of electronic data processing" OR DE "SUBJECTIVE transfer function method" OR DE "SUPERPOSITION principle (Physics)" OR DE "SWITCHING theory" OR DE "SYSTEM identification" OR DE "SYSTEMS design" OR DE "TIME-domain analysis" OR DE "TRANSMISSION network calculations" OR DE "UNCERTAIN systems")

Scopus

Supplementary file 1: Full search strategy

(TITLE-ABS ((system* W/1 approach*) OR (system* W/1 engineering) OR (system* W/1 science) OR (system* W/1 methodology*) OR (system* W/1 thinking) OR (system* W/1 dynamic*) OR (system* W/1 model*) OR (system* W/1 whole) OR (system* W/1 complex*) OR (system* W/1 ergonomics) OR (system* W/1 analys*) OR (system* W/1 theor*) OR ("discrete event simulation") OR (sociotechnical) OR (socio-technical))) AND (TITLE-ABS (design* OR concept* OR creat* OR plan* OR devis* OR draft* OR propos*)) AND (TITLE-ABS (trial* OR longitudinal* OR (before W/3 after) OR ("interrupted Time series") OR control* OR ("systematic* review*") OR ("literature review*") OR meta-analys* OR metaanalys* OR ("case study*") OR ("case control*"))) AND (TITLE-ABS (healthcare OR ("health care") OR medic* OR ("health* service*") OR care OR nurs* OR (safety W/3 patient*) OR ("treatment outcome*") OR mortality OR morbidity OR (health* W/1 (quality OR safety OR efficien* OR efficac* OR performance* OR outcome* OR deliver* OR experience)))))

Limit to 2019, 2020

Supplementary file 2- Data extraction tables

Table 1 – Study source, year and systems aspects

	Study	Source	Year	Country	Systems -Approach**	Systems-Intervention***	Design	Risk
1	**Afsar-manesh et al.**[1]	Healthcare	2016	USA	1	1	0	0
2	**Allaudeen et al.**	Quality Management in Health Care	2017	USA	1	1	1	0
3	**Anderson et al.**	The Permanente Journal	2017	USA	1	1	1	0
4	**Bell et al.**	BMJ Tobacco Control	2017	UK	0	1	0	0
5	**Bhatt et al.**[3]	J. of Med. Syst.	2014	USA	1	1	0	1
6	**Bhutani et al.**[4]	J. of Obs., Gyn. & Neo. N	2006	USA	1	1	0	1
7	**Bowen et al.**	J. of Digital Imaging	2016	USA	1	1	1	0
8	**Bradley et al.**[5]	Int. J. of QHC	2011	Ethiopia	1	1	0	0
9	**Catchpole et al.**[6]	JAMA Surgery	2014	USA	1	1	1	0
10	**Chandrasekar et al.**	QJM: An Int. J. of Medicine	2017	UK	1	1	1	1
11	**Cochran et al.**	J. of Medical Systems	2018	USA	1	1	1	1
12	**DeFlitch et al.**	Health Env. Research & Design J.	2015	USA	1	1	1	1
13	**Dennerlein et al.**[7]	BMJ Occ. & Envir. Med.	2017	USA	1	1	1	0
14	**Gupta et al.**	J. of Oncology Practice	2018	USA	1	1	1	0
15	**Hathout et al.**[8]	Leadership in Health S.	2013	Canada	1	1	1	0
16	**Heymann et al.**[9]	Israeli Med. Ass. J.	2004	Israel	1	1	0	0
17	**Hultman et al.**	Annals of Plastic Surgery	2016	USA	0	1	1	0
18	**Huntington et al.**[10]	Bull. Of WHO	2012	Philippines	1	1	1	0
19	**Hwang et al.**[11]	E. J. of Emerg. Med.	2017	Korea	1	1	0	0
20	**Kane et al.**	Joint Com. J. Qual. & Patient Safety	2019	USA	1	1	1	0
21	**Khan et al.**	British Medical J.	2018	CANADA/USA	0	1	1	0
22	**Kottke et al.**[12]	The Permanente Journal	2016	USA	1	1	0	0
23	**Lick et al.**[13]	Critical Care Medicine	2011	USA	1	1	0	0
24	**Loh et al.**[14]	Int. J. of HCQA	2017	Singapore	1	1	1	1
25	**McGrath et al.**	IEEE J. of Biomedical & Health Infor.	2019	USA	1	1	1	1
26	**McKetta et al.**[15]	The Joint Co. JQ&PS	2016	USA	1	1	1	0
27	**Moran et al.**	E-Clinical Medicine	2018	UK	1	1	0	1
28	**New et al.**[16]	PLOS One	2016	UK	1	1	0	0
29	**Rateb et al.**[17]	Int. J. of HCQA	2011	Egypt	1	1	1	0
30	**Rothemich et al.**[18]	A. J. of Prev. Medicine	2010	USA	1	1	0	0
31	**Rustagi et al.**[19]	J. of AIDS	2016	Africa (3)*	1	1	1	0
32	**Ryan et al.**[20]	Drug & Alcohol Depend.	2006	UK	1	1	0	0
33	**Shultz et al.**[21]	A. J. of Public Health	2015	USA	1	1	1	0
34	**Srinivasan et al.**	Hospital Pediatrics	2017	USA	1	1	1	1
35	**Tetuan et al.**[22]	J. of Nursing Reg.	2017	USA	1	1	0	1

*Three African countries – Cote d'Ivoire, Kenya and Mozambique **Consideration of systems in the approach to developing the intervention ***Consideration of systems in the implementation of the intervention.

Supplementary file 2- Data extraction tables

Table 2 - Characteristics of studies [population and intervention]

Study	Clinical area	Participants	Health setting	Type of Systems Approach	How implemented	Length of time applied	Training to staff	Perception of Systems Approach	How developed
Afsar-manesh et al., 2016	Clinical Readmission rates	Staff (implementation) Patients (Data).	Whole Hospital-in General Medicine, General Surgery, Neurosurgery, Paediatrics, Orthopaedics	Comprehensive Lean methodology	System-wide leadership and promotion of improvement culture, patient-centeredness, process improvement and RCA in six clinical departments focused on reducing readmissions.	18 months	Created forum to share ideas and learn from colleagues and training in Lean principles.	System-wide with Lean principles	Used existing Lean principles
Allaudeen et al., 2017	Emergency care	ED patients and staff	University-affiliated department of veterans affairs medical centre	Lean-based multi-disciplinary initiative and PDSA	Delivered a rapid process improvement workshop to evaluate current processes, identified root causes of delays and developed counter-measures and standard work. The standard work was put into practice and monitored, feedback on success was obtained. Barriers to success were identified, and PDSA cycles were followed in response. Daily management systems to re-inforce, evaluate and refine standard work were also developed.	3 years 1yr pre-intervention period; 3yrs post-intervention period (this appears to include 1yr implementation period)	Not specified	Lean-based and multi-disciplinary	Standard approach – Lean
Anderson et al., 2017	Geriatric hip fracture	Geriatrics patients and staff including a clinical leadership team, clinical participants and senior management.	The University of Colorado hospital academic medical centre	"Step-wise framework for implementing a comprehensive geriatrics hip fracture program" involving twelve steps	A series of 12 steps, comprising elements such as: assembling a team, conducting a gap analysis, establishing reporting measures, designing and implementing interventions, and evaluating outcomes.	17 months Pre-intervention (1/1/2012 – 28/10/2014), Post intervention (29/10/2014 – 31/03/2016) Implementation period (03/2014 – 10/2014	Can't tell	Step-wise and comprehensive involving a wide range of stakeholders and taking account of local context.	Self-developed but seems to be informed by Kotter: Kotter JP. Leading change: Why transformation efforts fail. Harv Bus Rev 2007 Jan:1-10.
Bell et al., 2017	Antenatal care (smoking	Pregnant women	Eight acute NHS hospital trusts and 12	"BabyClear" – a complex intervention	Training for staff in participating agencies in skills, supporting	4 months	Training provided for staff in participating	Complex intervention, change in overall system of care - Multi-agency referral	Developed by Tobacco Control Collaborating Centre, part of a larger

Supplementary file 2- Data extraction tables

	cessation among pregnant women)		local authority areas in North East England	comprising a package of measures designed to support implementation of national guidance	materials, and implementation of referral pathway.	Implementation between 11/2012 and 07/2013 Pre and post-intervention	agencies in CO monitoring, communication skills, skills training	pathway with follow-up protocol	Improving Performance in Practice programme.
Bhatt et al., 2014	Operating Rooms	Nursing staff, ORs	Academic Medical Centre	ACGME Core Competency of Systems-based Practice	Process redesign involving problem definition, process changes and a multidisciplinary TT team and through horizontal Integration.	17 days	Intervention trialed. Surgical and TT team trained to implement the new system.	ACGME Systems-based Practice Team working and coordination.	Used existing ACGME Systems-Based Practice Pre intervention process analysed using structured approach.
Bhutani et al., 2006	Maternity & Neonatal – new-born Jaundice	Well babies discharged as healthy, Patients' parents, Paediatricians , Paediatric nurses, Home care nurse agencies, Lactation support services,	Semi-private urban birthing hospital	Systems approach to Clinical Condition Management	Incremental chronological adoption of each element: a) 1990-1992 b) 1993-1995 c) 1996-1998 d) 1999-2000 Assessment of entire process 2001-2003 Incremental implementation of a systems approach that incorporated a hospital policy to (a) authorize nurses to obtain a bilirubin (total serum/ transcutaneous) measurement for clinical jaundice, (b) universal pre-discharge total serum bilirubin (at routine metabolic screening), (c) targeted follow-up, using the bilirubin nomogram (hour-specific, percentile-based total serum bilirubin/ transcutaneous bilirubin), and (d) an organized institutional systems-based management of newborn jaundice	12 months	Parent education	An approach that relies on 1. Visual recognition 2. Measurement of bilirubin 3. Lactation and nutrition support 4. parent education including follow-up and is considered Systematic Multifactorial An 'approach that does not deteriorate over time and has institutional memory	Incremental changes to managing treatment of jaundice in new-borns Developed through literature review Systematisation of approach (algorithm generation)
Bowen et al., 2016	Stroke care	Stroke patients	Grady Memorial Hospital - Single centre, hospital, stroke centre	Multi-stakeholder process mapping to inform problem identification involving value stream mapping	Workflow process map was developed over a period of two months involving paging dispatcher, university call centre and emergency medical services manager. Included working with	32 days Pre-intervention (April 20 – May 6 2014),	Can't tell	Multiple stakeholder involvement in mapping processes to inform improvement - value stream mapping (Lean)	Standard method – process mapping

Supplementary file 2- Data extraction tables

					equipment vendor to test and confirm problem identified and supply appropriate equipment.	Intervention (May – Sept. 2014), Post-intervention (Sept. 17 – October 19 2014)			
Bradley et al., 2011	Primary care	Primary Healthcare Units (PHCU) – Patients	Primary care in Rural Ethiopia	The Ethiopian Millennium Rural Initiative "By systems-based, we mean healthcare improvement efforts that target all patients rather than those with specific diseases and that can be standardized and replicated across the country over time."	Through the elements of EMRI model: (i) improving the infrastructure of health centres (i.e. water, electricity, physical infrastructure and equipment), (ii) improvement in the supply chain (e.g. transport of specimens and results follow-up), (iii) human resource capacity building through health worker training and on-site clinical mentoring, (iv) developing a system to improve referrals between health posts and health centres and (v) community education and mobilization	18 months	Approach involved community education and mobilization Health worker training and onsite clinical mentoring.	A focus on health infrastructure, supply chain, human resource, between centre referral systems and community education and mobilization	Part of national health sector development efforts. No specific details As part of the Ethiopian Millennium Rural Initiative
Catchpole et al., 2014	Trauma care	Trauma Patients	Nonprofit, Academic tertiary care medical centre	Although the paper applies Human Factors Engineering, there is no clear emphasis on such an application as being part of systems engineering or systems approach. Yet, they unintentionally referred SEIPS and PDSA (iterative)	A multidisciplinary team was brought together for one and a half days to define problems and identify solutions. The main problem areas were identified, and a range of potential solutions to each were generated. Then, a short list was generated based on practical considerations or the projected time needed for implementation. This short list was framed within the components of the SEIPS model. After the meeting, members of the ED and trauma teams were invited to discuss the short list and be involved in the studies. As implementation moved forward, they used small, iterative PDSA to develop each intervention to a level	5 months	None	Unintentional. SEIPS just to frame potential solutions, to ensure coverage of task, team, environment and technology.	Used existing SEIPS human factors model

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					where it was practical and deliverable.				
Chandrasekar et al., 2017	Acute Kidney Injury	All medical inpatients at a single UK hospital	A university hospital in the UK	'QI Methodology' including driver diagrams, pareto charts and statistical process analysis Also includes a range of interventions involving risk assessment tools, early identification using automated alerts, development of an intervention bundle, formation of an outreach support team staff engagement and patient and family empowerment.	A multi-disciplinary project team was given remote QI training and met at a weekly huddle. Preparation strategies included mapping stakeholders, patient journeys and current processes. 3 years of data were analysed, a driver diagram and standard QI charter were developed to guide project. Also included: - staff education and awareness program, - development of a patient specific electronic alert to prompt diagnosis - implementation of a memorable AKI care bundle (ABCDE-IT), - creation of a new dedicated AKI outreach team - patient and family empowerment	34 months – Pre-intervention (Jan. 2011-oct. 2013), Post-intervention (Oct. 2013 – Jul. 2016) Entire project lasted 5 years	Remote training in QI for the team plus weekly huddles. Also staff engagement package, posters, seminars for key staff groups, formal and informal awareness events in the hospital	The project recognises multiple elements of the system as contributing to the problem (as evidenced by their driver diagram). The intervention attempted to address multiple elements within the system: staff knowledge, electronic patient health record prompts, new packages/care processes for patients with AKI Stakeholder mapping, mapping of patient journeys and identification of key care processes.	The project was triggered following a mortality analysis at the trust and joint collaboration with Institute of Healthcare Improvement in Boston, USA. The team went through remote training in QI, sought to influence business intelligence reporting and met at a weekly huddle.
Cochran et al., 2018	Emergency room	Patients, nurses and a team of ER and system engineering specialists	Franciscan Health Indianapolis – a general medical and surgical centre	Collective System Design (CSD) methodology involving PDCA – a systems engineering methodology, which recognises systems as the amalgamation of four key elements: Work/Actions, Structure, Thinking and Tone.	Senior leadership and ER team worked to identify the needs of internal and external customers, identified system boundaries, developed a CSD map and applied PDCA to design the relationships on the map for the purpose of implementation. Electronic logs of the medical centre was used to establish baseline.	8 months Pre-intervention (8 months), Post-intervention (8 months)	Can't tell	Recognition of a system as an amalgamation of four key elements that are always present and completely interrelated – work/actions, structure, thinking and tone or culture. Also defining stakeholders and the system boundary, understanding the needs of stakeholders, and determining the functional requirements to develop solutions.	Can't tell
DeFlitch et al., 2015	Emergency departmen t	Patients and staff	A suburban, tertiary care, academic ED, with paediatric and adult level 1 trauma.	"Engineering techniques" including defining a study team, process mapping, Discrete Event Simulation modelling and detailed design considerations	A study team was setup to carry out project. The team examined the operational data from our ED information system (EDIS), charted patient arrival patterns, conducted interviews of staff, observed staff with patients, and mapped the ED processes of care. Proposed model	3 years Pre-intervention (July 2005 – June 2006), Post-intervention	Student educational training	Engineering techniques that involve process mapping and simulation modelling and visualization of the operation of the system.	Use of existing tools - process mapping and simulation plus self-developed processes.

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				leading to the Physician directed Queuing (PDQ) model.	was tested in a simulation and piloted before implementation.	(July 2009 – June 2010) Intervention (July 2006 – June 2009)			
Dennerlein et al., 2017	Patient Handling and mobilisation	Direct Patient Care Workers	Hospital-wide -at 2 hospitals	A broad stakeholder engagement from senior level down, new lifting equipment across hospital, new processes and group training and one-to-one coaching and mentoring for staff	High-level buy-in with a multidisciplinary oversight committee chaired by the Associate Chief Nurse of Quality and a Collaborative Coordination Committee including Associate Chief, Occupational health ergonomists and nurse business officer The hospital expanded its investment in ceiling lifts, slings, sit-to stand devices and etc. The coordinating committee developed processes ensuring that all equipment was in working order and portable devices were stored on the units and readily available for use.	12 months	Yes, Programme training was provided to all nurses, nurse directors and patient care assistants. An external consultant provided an online introductory module, followed by group training and one-on-one coaching and mentoring at the bedside.	System-wide and multi stakeholder and multi processes Hospital-wide, and involvement of different stakeholders and multi components	Developed by a committee to include key component identified by previous systematic reviews, including an organisational policy aimed at reducing injuries, investment in equipment broad-based training within the context of providing tools and risk assessment
Gupta et al., 2018	Chemotherapy	Healthcare staff and patients	Parkland health and hospital system – a large public hospital in the USA	A multi-disciplinary team delivering PDSA including process mapping.	A multi-disciplinary team involving nurses, pharmacists, physicians, QI training programme coach, QI experts, IT analysts, unit secretary and patient representatives conducted assessment of existing waiting times, identified factors and conducted two cycles of PDSA.	6 months Pre-intervention (Jan. – Feb. 2017) Intervention (PDSA 1, Aug. – Sept. 2017; PDSA 2, Sept. – Oct. 2017) Post-intervention period not defined.	Can't tell	Focused on developing a preadmission process that streamlined patient evaluation on admission and improved communication.	Existing method – PDSA and process mapping.
Hathout et al., 2013	Sleep disorders	Healthcare staff	Province-wide, Manitoba, Canada	Stakeholder engagement, problem exploration, process mapping,	A project steering committee setup decided what is to be done. Consultations took place with stakeholders, staff, patients, administrators and managers.	18 months	Wide consultations, but PSG training was recommended as a result of the study	Stakeholder involvement, deep exploration of problem and system understanding (system	A multidisciplinary team was convened to improve the system to meet the population's needs.

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				exploration of systems drivers and value and objectives of services	A multi-disciplinary team was convened to improve the system to meet the population's needs. They articulated a vision, conducted a demand analysis, and then described the current state of the system. Using the demand analysis and their understanding of the current state they defined the desired state and worked through the process changes requirements to bridge the gap from the current state to the desired state.			drivers), its problems and stakeholders' needs.	
Heymann et al., 2004	Antibiotic overprescribing	Healthcare professionals-Staff	Maccabi Healthcare services, a Health Maintenance Organisation (HMO) serving 1.5M patients	Previously developed Systematic Inventive Thinking (SIT). Bases on "Creativity as an exact Science" by Genrich Altschuler	A multidisciplinary group was formed to work through the SIT steps – problem reformulation, general search strategy selection and application of idea-generation techniques. Results launched through national media campaign.	14 months	Not reported	Multiple stakeholder engagement, deep problem exploration, with focus on creative solutions. Unintentional, it has the elements of systems thinking, but the paper uses a systematic approach to solve complex problems	Based on previous work
Hultman et al., 2016	Breast reconstruction	Healthcare staff and patients	Academic medical centre of the University of North Carolina Hospitals	Lean-Six Sigma – using standard DMAIC model	A multi-disciplinary project team involving microsurgeons, anaesthesiologists, circulating nurses, surgical assistants liaising with other stakeholders.	24 months Pre-intervention (24 months), Intervention (10 months), Post-intervention (24 months)	Some team members were trained in six sigma with blue, green and yellow belts.	Six Sigma with multiple stakeholders	Existing method – Six sigma
Huntington et al., 2012	Maternal Health	Women's health teams	Health systems reform in a province in the Philippines involving two tertiary hospitals , 20 first level referral health facilities.	National initiative - National Safe Motherhood Programme. Seems influenced by WHO health systems strengthening principles	Implemented through national Department of Health initiatives Speed of implementation seems to have been the interventional factor. Fast in one province; normal in five provinces.	4 years	Intervention province reported that 74% of the referral providers had completed competency-based clinical training programme. No information on clinical training was available for the comparison provinces.	Holistic understanding of a system's building blocks, identifying where a system succeeds, where it breaks down and what kinds of integrated approaches will strengthen the overall system.	No details reported. Appears influenced by WHO health systems strengthening principles.

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			Twelve rural health units. One barangay (neighbourhood or village) health station						
Hwang et al., 2017	Cardiac care	Patients	Multiple institutions in the chain of survival of cardiac arrest patients – community to hospital	System-wide CPR programme for OHCA patients developed by lead Hospital.	Started by identification of weak points in chain of survivor, CPR education sessions, improved records captured by EMS new protocol for ACLS at ED formulated by a multidisciplinary team.	12 months	CPR education for public at school and workplace.	"System-wide". Lots of emphasis on scope – who is involved – rather than how. Analysis of delivery system weaknesses in CA survival and multi interventions approach to address those weaknesses.	Developed in-house. No reference to any previous work.
Kane et al., 2019	Patient flow	Nursing bed managers, transfer line operators, patient pathway coordinators	A tertiary care hospital in Baltimore, USA	"A systems engineering approach" involving a steering group consisting of hospital CEO, CIO, COO, VP for medical affairs, Director of nursing, and project leaders. Involved working with external supplies and use of DES and ABS.	Governance structure and core leadership team set up for project, medical director playing a key leadership role. Core leadership group met weekly and drive strategic operational initiatives. There is also a dedicated data analytics team and a group of clinical representatives. Also involves partnership with GE Healthcare.	Not clear – it seems project started in 2014, various interventions implemented from 2014/15, 2016/17, 2018 and ongoing. Reported results based on preliminary data Entire project seems to have lasted 4 years	Can't tell	Specifically targeting patient flow throughout the hospital 'system'. Considers the context / wider system (e.g. outside treatment facilities). Considers key stakeholders, particularly in governance of the new system (see governance structure). Actively explores risks through two different types of complex simulation modelling.	Key stakeholders identified and then brought together to develop the command centre jointly. A new space was created so that key stakeholders could be physically collocated, SOPs created and then simulation modelling performed. Evaluation is still underway.
Khan et al., 2018	Paediatric inpatient unit	Patients, parents or caregivers, nurses, medical students and residents	Paediatric inpatient units in seven North American hospitals in USA and Canada	Co-production of intervention to standardise the structure of healthcare provider-family communication on family centred rounds.	A team of parents, nurses and physicians including health service researchers, medical educators, hospitalists, communication experts and health literacy experts coproduced the intervention to standardize healthcare provider-family communication on ward rounds ("family centered rounds"), which included structured, high reliability communication on bedside rounds emphasizing health	3 months - Pre-intervention (3 months), Intervention (9 months), Post - intervention (3 months)	A rounds training and learning programme for interprofessional team members.	Health service user centered (patients and families involved in production of the intervention). Intervention addressed multiple elements of the system i.e. targeted key stakeholders with education but also implemented process	Self-developed - A team of parents, nurses, and physicians, including health services researchers, medical educators, hospitalists, communication experts, and health literacy experts, coproduced the intervention—the Patient and Family Centered I-PASS

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					literacy, family engagement, and bidirectional communication.	Entire project lasted 25 months (December 2014 – January 2017)		changes, such as the mid-shift nurse-physician huddles. Intervention assessed across multiple domains, including reductions in medical errors and family experience.	
Kottke et al., 2016	Primary care - Coronary Heart Disease	Patients	Private, five-clinic primary care practice	Complex Adaptive Systems principles	Each clinic developed own system using systems' personnel including RN, Care Manager, IT staff and Clinic Assistant Care Coordinators. Activities related to patient care delivery, provider staff, staff education, training and tool development and information technology Through Team Based working.	6 months	Clinical service staff trained for use. Previsit planning tool. Patient education materials. Including clinical based skills and QI.	"1. health service delivery systems are complex adaptive systems, not mechanical systems, 2. Adoption of any system of care requires adaptation and reinvention and 3. The long-term survival of any system of care requires that a new process, at a minimum, does not threaten the viability of the overall system."	Using existing CAS theory to design interventions.
Lick et al., 2011	Cardiac Arrest	Patients	Community-based centres of excellence	"Take heart America programme". Community-based initiative involving 1. Widespread Cardiopulmonary resuscitation 2. Retraining of all emergency medical service personnel 3. Additional deployment of automated external defibrillators and 4. Protocol for transport to and treatment by cardia arrest centres.	Site coordinator appointed to work in lead hospitals in each of two counties. Coordinators established collaborations and implemented THA with city administrators, police and fire departments, school system administrators, survivors and survivor network organisations, ALS support team members, hospital administration and key clinicians in each Cardiac Arrest Centre (CAC).	6 months	Extensive Community CPR training, Public awareness, dispatcher instructed CPR. Advanced Life Support training for staff.	Emphasis appears to be on the wide coverage of the programme – community-side and multi-agency. Take Heart America (THA) model of improving care.	Developed by implementing all the high level 2005 American Heart Association (AHA) CPR and Emergency Cardiovascular Care Guidelines in a community-wide systems approach based on treatment models for other complex diseases such as HIV
Loh et al., 2017	Cataract Surgery	Patients	National tertiary specialist hospital	SEIPS Model/ PDSA	SEIPS used as framework for classification of problem, PDSA approach to improvement	6 months	Briefing of staff on data collection and weekly reminders	SEIPS framework	Existing approach Standard SEIPS model tailored to the case in question.

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					1. Retrospective study 2. Qualitative descriptions of incidents. 3. Applied SEIPS as a reference framework.				
McGrath et al., 2019	Postoperative surgical care& General medical inpatient care	Patients and staff including Nurses, Nurse Assistants, Occupational therapists, Physical therapists, Physicians	US Academic Health Centre	System-level design and analysis involving system design and validation, installation and education, operation and performance measurement	System design and validation phase was used to set goals for improvement based on organisational data and review of existing systems. Following elicitation of desired improvements and compilation of feature list, workshops were held with technical and clinical stakeholders to develop integration, installation, workflow and safety specifications and processes for selected system.	5 months - Pre-intervention (5 months), 2 months of intervention Post-intervention (5 months)	Education materials were created and delivered to staff to assist in understanding purpose, goals and to orient staff to new system, operation, workflows, and medical record processes.	Systematic technical and workflow design, implementation and performance measurement phases. Views the systems element as a preparation phase of exploration, piloting, and validation. Then moves into discrete implementation and measurement phases which seem separate to the systems element.	Not clear. No specific tools or approaches mentioned, and no clear grounding in systems literature.
McKetta et al., 2016	Paediatric Cardiac procedures	Physicians Nurses Technicians Improvement specialists	The Cardiac Centre at a Children's Hospital	A Discrete Event Simulation together with traditional QI involving a multidisciplinary team using a four-step framework – Define, Diagnose, Test and Implement, and Sustain. Including PDSA	Implementation led by a multidisciplinary team of physicians, nurse practitioners, nurses, technician and improvement support using an in-house framework- Define, Diagnose, Test and Implement, and Sustain. Tests were evaluated using PDSA cycles.	4 months	Not reported Daily debrief to sustain performance	Discrete Event Simulation (DES) as a tool for analysing complex systems Change management in complex systems. DES combined with QI a model for addressing this. Aim to maintain throughput during resource restriction (closed procedure suite).	A previously developed DES model was used and a four-step improvement framework developed in-house.
Moran et al., 2018	Major trauma	Population of England and wales- All hospitals in England and Wales (primary analysis done on 35 'constant submitter' units)	UK NHS in England and North Wales	Trauma systems – Systematic trauma care on a national basis.	NHS reorganisation creating a series of Regional Networks designated as Major Trauma Centres, with funding through a 'Best Practice Tariff' only available to MTCs over and above the normal funding for such patients. Data collected longitudinally through the Trauma Audit and Research Network (TARN).	4 years - Pre-intervention (Apr. 1st 2008 – Mar. 31st 2009) Intervention (2009/10 – 2011/12) Post-intervention (2013/14-2016/17)	Can't tell	Rationalised provision of trauma care through coordinated networks with an MTC hub.	Comparison with experience in the US. No clear reference to systems thinking literature.

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New et al., 2016	Trauma & Orthopaedics	Theatre staff	The Orthopaedic trauma theatre of a UK hospital Trust	A two-step intervention – one-day Lean training followed by 6 months coaching. Training covered Lean principles – Muda, Poka-Yoke, Genchi Genbutsu, Kaizen, flow, JIT, respect and teamwork, process mapping, PDCA cycles and a philosophy of continuous participative experimental improvement. Then a six-month improvement project.	The multidisciplinary team decided on improvement project after training and carried it out with support from experts.	6 months	A whole day training for a multidisciplinary staff team and practical training for project team during the improvement process Training in lean theory and methods with subsequent support and encouragement: one day training with light-touch coaching for six months (nurses, surgeons, anaesthetists and administrators)	A comprehensive Lean approach.	Existing method - Lean
Rateb et al., 2011	Health Insurance Organisation (HIO), pre-employment medical fitness check-up	Doctors, nurses, administrative staff, and customers	Egypt HIO / community, Medical fitness testing.	Business Process Re-engineering focusing on Structure, Process and Outcome. Systems approach appears to mean everything from building renovation to customer and staff satisfaction	Conducted brainstorming sessions involving stakeholders, decision makers, service providers and beneficiaries. Randomly selected six centres to take part in re-engineering phase which was implemented in three stages.	Can't Tell	New services, processes and standards introduced. IT training for staff	The entirety of Structure, Process and Outcome of care Business Process Re-engineering (BPR)	Approach developed by team using BPR concepts and Donabedian's model
Rothemich et al., 2010	US Family Practice / Public Health: smoking cessation	Adult smokers and Family physicians, general internists, nurse practitioners, physician assistants.	16 primary care practices	Called QuitLink Intervention. Limited details provided. Described as using paper-based, systems approach to identify smokers, provide advice to quit, and assess willingness to quit. Includes supporting	Selected practices were randomised into a control group and an intervention group. A nurse liaison provided training to all rooming staff at intervention practices on QuitLink implementation procedures. 1. Practice recruitment via researchers. 2. 2-month 'wash-in period' to incorporate methodology,	1 months	Training for staff, office manager, and some clinicians. Nurses and medical assistants trained in the QuitLink implementation given a customised 'stamp', protocol and process explained.	Ensuring communication from clinician to quitline and feedback from quitline to clinicians or a systematised population-health intervention with multiple points of action.	Self-developed: Synthesised from an evidence base around smoking cessation services – the approach used designed to address most of the perceived deficiencies in previous attempts.

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				willing smokers too access quitlines and communicate feedback from quitline to clinicians	install resources (quitline stamp and fax referral), train staff, obtain baseline data, and define analytic strata 3. Comparison period involving ongoing outcome measurement				
Rustagi et al., 2016	HIV AIDS	Healthcare staff and Patients	Mother-to-child HIV transmission prevention services in three countries in Africa – Cote d'Ivoire, Kenya and Mozambique	The Systems Analysis and Improvement Approach (SAIA) – a 5-step, iterative package of systems analysis and improvement tools developed using multiple systems engineering techniques including continuous quality improvement.	4-day workshops were held at each intervention facility to introduce and prepare staff for the intervention, follow-up visits were conducted weekly for 4 weeks, biweekly for 8 weeks after and then monthly visits thereafter or as needed by staff.	9 months	Training and support regular support provided for staff	Approach targets wider system from district level to local processes and action. Tools in SAIA include Cascade analysis tool – excel spreadsheet for quantitative analysis of patient flows, Value Stream Mapping (VSM) and PDSA	Self-developed based on multiple existing systems engineering tools.
Ryan et al., 2006	Alcohol detoxification	Service users	Manchester Alcohol Service (MAS) In-patient detoxification service	A whole systems approach to alcohol services – A collaborative working between multiple organisations	Implementation of approach occurred with new contracts issued to each of the providers: in-patient and home detoxification, community treatment, day care and access into rehabilitation services and other wrap-around services	Can't Tell	No	Collaborative working between organisations that individually addressed different parts of the needed service.	Previously developed and implemented MAS system. Current study only provides retrospective evaluation.
Shultz et al., 2015	Vaccine administration	Physicians and staff	5 Family Medicine Clinics and 4 Internal Medicine Clinics (as control)	Sequential and linked PDSA/Adjust cycles. A consensus-based framework that addresses the process of care.	Using collaborative working, five community-based family medicine clinics at the university of Michigan modified a point-of-care decision-support system for to improve administration and documentation Tetanus, diphtheria and acellular pertussis vaccines for patients.	Two years	Clinicians, nurses, medical assistants and support staff were trained to use the newly developed Automated Clinical Reminder (ACR) system.	A focus on Structure (physical environment and context of care), process (actions and procedures associated with the delivery and documentation of care) taking the needs of people into account.	An existing Automated Clinical Reminder (ACR) system was modified through consultations with clinicians, nurses, medical assistants, and support staff from each clinic.
Srinivasan et al., 2017	Paediatric inpatients	1 -23 month old Babies and parents and paediatric hospitalists,	Emergency department and inpatient unit of a 280-bed tertiary care, free-	Driver Diagram plus three cycles of PDSA involving stakeholder surveys focusing on changing clinician	A stakeholder survey was conducted and a multi-disciplinary team was set up. Stakeholder responses were turned into a driver diagram and projects for 3 PDSA cycles with a 3 week period at the	3 weeks - Pre-intervention (Jan. 2015 – Apr. 2015),	Face to face by study team to clinical providers during routine meetings, email communication to	Systems changes seem conceptually confined to process changes (NG feeding tube order set) and physical changes (stocking of ED with appropriate	Existing method – PDSA and Driver Diagram. Explicit reference to PDSA cycles but not to systems thinking/approaches

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		paediatric emergency medicine physicians, nurses, residents, interns, and nurse practitioners.	standing children's hospital	behaviour through both education, reinforcement and encouragement.	end of each cycle and a wide engagement of stakeholder with results of each cycle.	Intervention (Jan. 2016 – Apr. 2016) Post-intervention period unclear appears to be 3 weeks.	those not attending meetings, posters in clinical areas, pocket cards for clinicians, parental information sheets, walk-throughs 3 times per week to trouble shoot.	supplies). However, the driver diagram denotes different interventions having an impact on multiple possible drivers, more consistent with a systems thinking approach.	
Tetuan et al., 2017	Medication administration	Nurses	Integrated health care systems comprising primary and speciality clinics, and a 568-bed acute care hospital.	Systems Thinking Education Programme (STEP)	Medication huddles and monthly Organisation-wide education for 1yr. 1. Staff training (over 12 months) on systems thinking 2. Medication huddles 3. Observation audits of the medication administration process	12 months	Monthly training for 1yr Training of trainers for medication huddles, and direct subsequent training of other staff.	System-wide: Multifaceted intervention based around a definition of systems thinking as "the ability to recognise, understand, and synthesis the interactions and interdependencies in a set of components designed for a specific purpose".	Literature review of systems thinking, error detection, and safety culture.

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Table 3 – Characteristics of study cont. [Design, and other quality issues]

Study	Study Design	Baseline type (Prospective – study data OR Retrospective-routine data	Blinding of outcome measure (Yes, No, Can't Tell)	Funding source
Afsar-manesh et al., 2016	Before, During & After	Retrospective routine data	Can't Tell?	No external funding
Allaudeen et al., 2017	Before, During and After/ Concurrent Control	Retrospective routine data	Can't tell	Not reported
Anderson et al., 2017	Before, During and After	Retrospective routine data	Can't tell	Not reported
Bell et al., 2017	Before, During and After	Retrospective routine data	Can't tell	This article presents independent research funded by the NIHR School for Public Health Research (SPHR). NIHR SPHR is a partnership between the Universities of Sheffield, Bristol, Cambridge, Exeter, University College London; The London School for Hygiene and Tropical Medicine; the LiLaC collaboration between the Universities of Liverpool and Lancaster; and Fuse, the Centre for Translational Research in Public Health, a collaboration between Newcastle, Durham, Northumbria, Sunderland and Teesside Universities. Fuse is a UK Clinical Research Collaboration (UKCRC) Public Health Research Centres of Excellence, which receives funding from the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, and the National Institute for Health Research
Bhatt et al., 2014	Before, During & After	Retrospective routine data & Prospective study data	Can't Tell?	Lead author funded by hospital
Bhutani et al., 2006	Before, During & After	Prospective study data	Can't Tell?	Eglin fund and the New-born Paediatric Research Fund
Bowen et al., 2016	Before, During and After	Retrospective routine & Prospective Study data	Can't tell	Not reported
Bradley et al., 2011	Before, During & After	Retrospective routine data	Can't Tell?	The Children's Investment Foundation Fund
Catchpole et al., 2014	Before, During & After	Retrospective routine data & Prospective study data	No	Telemedicine and Advanced Technology Research Centre of the US Department of Defence
Chandrasekar et al., 2017	Before, During and After	Retrospective routine data	Can't tell	Not reported
Cochran et al., 2018	Before, During and After	Retrospective routine data	Can't tell	Not reported
DeFlitch et al., 2015	Before, During and After	Retrospective routine data	Can't tell	Received no financial support for the research authorship, and/or publication of this article.

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Dennerlein et al., 2017	Before, During & After	Retrospective routine data	Can't Tell?	National Occupational for Safety and Health for the Harvard T.H. Chan School of Public Health Centre for Work, Health and Wellbeing; National Institute of Arthritis and Musculoskeletal and Skin Disease of the National Institute of Health; Partners HealthCare
Gupta et al., 2018	Before, During and After	Retrospective routine data	Can't tell	Not reported
Hathout et al., 2013[8]	Before, During & After	Prospective study data	Can't Tell?	Not reported
Heymann et al., 2004[9]	Before, During & After	Retrospective routine data & Prospective study data	Can't Tell?	Not reported. Note – lead author works for HMO, programme evaluated by HMO
Hultman et al., 2016	Before, During and After	Retrospective routine data	Can't tell	Not reported
Huntington et al., 2012	Before, During & After /Concurrent Control	Retrospective routine data	Can't Tell?	World Bank; Manila Country Office; Department of Reproductive Health and Research, WHO, Geneva
Hwang et al., 2017	Before, During & After	Retrospective routine data	Can't Tell?	One author received grants from College of Medicine, Korea University and the Korea Centres for Disease Control and Prevention.
Kane et al., 2019	Before, During and After	Retrospective routine data*	Can't tell	Not reported
Khan et al., 2018	Before, During and After	Prospective Study data	Yes Yes	This project was supported by grant GSR-1306-03556 from the Patient-Centered Outcomes Research Institute (principal investigator: CPL). AK was supported by grant K12HS022986 from the Agency for Healthcare Research and Quality (principal investigator: Jonathan Finkelstein; Boston Children's Hospital, Boston, MA). JDB was supported by grant 5T32HS00063-21 from the Agency for Healthcare Research and Quality (principal investigator: Jonathan Finkelstein). The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the report; or in the decision to submit the article for publication. Researchers were independent from funders and all authors had full access to the data and can take responsibility for the integrity of the data and the accuracy of the data analysis.
Kottke et al., 2016	Before, During & After	Retrospective routine data	Can't Tell?	National Heart and Lung Institute, National Institutes of Health, Bethesda, MD. Grant #R18HL096563 was the sole financial support for this project.
Lick et al., 2011	Before, During & After	Retrospective routine data and Prospective study data	No	Funding support from Medtronic Foundation, Medtronic Corporation, the CentraCare Health Foundation and the Unity and Mercy Hospital Foundations
Loh et al., 2017	Before, During & After	Retrospective routine data	No	Not reported
McGrath et al., 2019	Before, During and After/ Concurrent Control	Retrospective routine & Prospective Study data	Can't tell	Agency for Healthcare Research & Quality (AHRQ)
McKetta et al., 2016	Before , During & After	Retrospective routine data & Prospective study data	Can't Tell	Not reported
Moran et al., 2018	Before, During and After	Retrospective routine data	No	Performed independently without external funding

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New et al., 2016	Before, During & After /Concurrent Control	Prospective study data	Can't Tell	NIHR Programme Grant for Applied Research (RP-PG-0108-10020)
Rateb et al., 2011	Before, During & After	Retrospective routine & Study data	Can't Tell	Not reported
Rothemich et al., 2010	Concurrent Control (RCT)	Prospective study data	No	Funded by grant from the Agency for Healthcare Research and Quality (AHRQ) (5R21HS014854-02). One author owns stock in a Quitline service provider.
Rustagi et al., 2016	Before, During & After /Concurrent Control (RCT)	Retrospective routine & Study data	Can't Tell	Funded by Eunice Kennedy Shriver National Institute of Child Health and Human Development, the National Institute of Allergy and Infectious Diseases, the National Cancer Institute, the National Institute on Drug Abuse, the National Heart, Lung and Blood Institute and the National Institute on Aging of the US National Institutes of Health under award numbers R01HD075057 and P30AI027757 (awarded to the University of Washington Center for AIDS Research), as well as the Doris Duke Charitable Foundation's African Health Initiative (awarded to K.S. and M.F.C.), and the Fogarty International Center grant number K01TW009207 (awarded to K.S.).
Ryan et al., 2006	Before, During & After	Retrospective routine data	Can't Tell	Funded by grant from Turning Point
Shultz et al., 2015	Before, During & After/Concurrent Control	Retrospective routine data	Can't Tell	Not reported
Srinivasan et al., 2017	Before, During and After	Retrospective routine data	Can't tell	National Institutes of Health Clinical and Translational Science Award grant UL1 TR000448
Tetuan et al., 2017	Before, During & After	Prospective study data	Yes, for medication errors	Not reported

Supplementary file 2- Data extraction tables

Table 4a – Numbers and numerical values – Patient outcomes: Studies with Before, During & After Designs

Study	Outcomes measures	After	During	Before	P-values
Afsar-manesh et al., 2016	Overall 30-day readmission rate Subgroups: General Medicine General Surgery Neurosurgery Paediatrics Orthopaedics	11.3%, [n or N not reported] 16.7% 7.8% 7.4% 9.8% 6.8%	- - - - - -	12.1%, [n or N not reported] 17.9% 9.9% 9.6% 10.8% 8.0%	*P*< 0.05 *P*< 0.05 *P*< 0.05 *P*< 0.05 *P*< 0.05 *P*< 0.05
Allaudeen et al., 2017	-	-	-	-	-
Anderson et al., 2017	Laboratory evaluation for secondary causes of osteoporosis - n/N (%): Completed blood cell count Basic metabolic panel with calcium Hepatic function panel 25-hydroxyvitamin D Pharmacotherapy on discharge - n/N (%): Calcium Vitamin D Antiosteoporosis Follow-up appointment completed within 30 days- n/N (%): PCP (Internal to system) Metabolic Bone Clinic Orthopedics Clinic	 116/117 (99%) 111/117 (95%) 104/117 (89%) 104/117 (89%) 116/117 (99%) 112/117 (96%) 70/117 (85%) 13/117 (45%) 32/117 (28%) 96/117 (82%)	 - - - - - - - - - -	 154/154 (100%) 151/154 (98%) 74/154 (48%) 105/154 (68%) 84/154 (55%) 107/154 (70%) 34/154 (24%) 14/154 (26%) 4/154 (3%) 118/154 (77%)	 *p=1.000* *p=0.963* *p<0.001* *p<0.001* *p<0.001* *p<0.001* *p<0.001* *p=0.363* *p<0.001* *p=0.175*
Bell et al., 2017	Probability of quitting smoking by delivery date: Adjusted Odds Ratio (95% CI)	 1.81 (1.54 to 2.12)	 -	 0.13 (0.09 – 0.19)	 *p<0.001*
Bhatt et al., 2014	-	-	-	-	-
Bhutani et al., 2006	Readmission rates for intensive phototherapy – n/N (%) [Rates estimated from graph. "Before" rate is for 1998. 1994-95 values available] Extreme hyperbilirubinemia	19/3,227 (0.59%) 0	27/3,168 (0.85%) 0	94/8,186 (1.15%) 0	- -
Bowen et al., 2016	-	-	-	-	-
Bradley et al., 2011	-	-	-	-	-

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Catchpole et al., 2014	-	-	-	-	-
Chandrasekar et al., 2017	Reduction in in-hospital AKI mortality pre – post project 30-day mortality rate for AKI patients	23.2% 25.9% decrease	-	Data not given Data not given	*P<0.0001*
Cochran et al., 2018	Patient satisfaction with quality of care Percent of patients leaving without treatment	41st percentile [n or N not reported] 0.26%, [n or N not reported]	- -	20th percentile [n or N not reported] 1.50%, [n or N not reported]	*not reported* *not reported*
DeFlitch et al., 2015	Left without being seen Patient satisfaction	0.6%,[n or N not reported] 85th percentile [n or N not reported]	- -	5.7%, [n or N not reported] 17th percentile [n or N not reported]	*p<0.0001* *p<0.0001*
Dennerlein et al., 2017	-	-	-	-	-
Gupta et al., 2018	-	-	-	-	-
Hathout et al., 2013	Patients on recommended treatment	70%, n or N not reported	-	55%, n or N not reported	-
Heymann et al., 2004	-	-	-	-	-
Hultman et al., 2016	Partial or total flap loss – n/N (%) Take-back rates – n/N (%) Overall complication rates	*3*/46 (7%) *11*/46 (23.9%) *14*/46 (30%)	*3*/27 (11%) *6*/27 (20.7%) *9*/27 (33.3%)	*1*/39 (3%) *8*/39 (20.5%) *14*/39 (35.9%)	*Not significant* *Not significant* *Not significant*
Huntington et al., 2012	Number of maternal deaths/yr at intervention site– n/N (%) Maternal Mortality Rate (MMR)	18/*15,789* (0.114%) 114	24 [N not reported]	42/*16,535* (0.254%) 254	Not reported
Hwang et al., 2017	Good neurologic recovery at discharge (CPC 1, 2) –n/N (%) Number of patients admitted to ICU – n/N (%) Successful TH in cases of comma – n/N (%) Discharged from hospital alive – n/N (%)	24/282 (8.5%) 101/282 (35.8%) 33/96 (34.4%) 51/282 (18.1%)	5/117 (4.3%) 31/117 (26.6%) 2/31 (6.5%) 15/117 (12.8%)	6/182 (3.3%) 29/182 (15.9) 1/27 (3.7%) 16/182 (8.8%)	*p=0.001* *p*<0.001 *p*<0.001 <0.05
Kane et al., 2019	-	-	-	-	-
Khan et al., 2018	Family experience during rounds – top-box scores(95%CI): Understood what was said on rounds	N = 890 62.8% (53.7% - 71.1%)	-	N = 947 53.9% (44.6% - 63.0%)	*p=0.03*

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	Medical team explained well possible changes to child's condition	59% (?)	-	56% (?)	*not available*
	Satisfied with opportunity to ask questions on rounds	72% (?)	-	69% (?)	*not available*
	Medical team listened to family concerns	72% (?)	-	67% (?)	*not available*
	Family was included in decision making	59% (?)	-	56% (?)	*not available*
	Family felt important in their role on rounds	57% (?)	-	50% (?)	*not available*
	Family respectfully spoken to on rounds	79% (?)	-	78% (?)	*not available*
	Quality of communication during morning rounds	66% (?)	-	62% (?)	*not available*
	Family experience after rounds - top-box scores(95%CI):	N = 890		N = 947	
	Satisfaction with frequency of updates on child	54% (?)	-	49% (?)	*not available*
	Quality of update explanations	60% (?)	-	58% (?)	*not available*
	Inclusion in decision making later in day	55% (?)	-	53% (?)	*not available*
	Written communication - top-box scores(95%CI):	N = 890		N = 947	
	Frequency of written updates	33.7% (23.9% - 45.2%)	-	15.6% (8.9% - 25.9%)	*p<0.001*
	Understood written updates provided	57.9% (46.4% - 68.6%)	-	46.5% (34.2% - 59.3%)	*p=0.04*
	Communication with doctors - top-box scores(95%CI):	N = 890		N = 947	
	Shared understanding with doctors of medical plan	59.2% (49.9% - 67.8%)	-	54.0% (44.6% - 63.1%)	*p=0.14*
	Doctors addressed family concerns	65.9% (56.8% - 73.8%)	-	61.8% (52.5% - 70.3%)	*p=0.22*
	Doctors made family feel an important part of healthcare team	60.9% (49.2% - 71.4%)	-	57.7% (45.9% - 68.7%)	*p=0.34*
	Communication with nurses - top-box scores(95%CI):	N = 890		N = 947	
	Shared understanding with nurses of medical plan	65.4% (58.4% - 71.8%)	-	55.3% (48.0% - 62.4%)	*p=0.02*
	Nurses addressed family concerns	70.2% (62.9% - 76.6%)	-	61.2% (53.4% - 68.5%)	*p=0.02*
	Nurses made family feel an important part of healthcare team	70.7% (61.4% - 78.6%)	-	63.2% (53.5% - 71.9%)	*p=0.04*
	Teamwork amongst providers - top-box scores(95%CI):	N = 890		N = 947	
	Teamwork amongst doctors and nurses	62% (?)	-	59% (?)	*not available*
	Understanding - top-box scores(95%CI):	N = 890		N = 947	
	Understood overall reason for child's hospital stay	72% (?)	-	72% (?)	*not available*
	Understood what needed before child can return home from hospital	66% (?)	-	62% (?)	*not available*
	Overall quality - top-box scores(95%CI):	N = 890		N = 947	
	Overall quality of child's care	73% (?)	-	69% (?)	*not available*
	Quality of communication during hospital stay	59% (?)	-	55% (?)	*not available*

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	Overall medical errors: n/N (%) Rate/1000 patient days (95%CI) Non-harmful errors: – n/N (%) Rate/1000 patient days (95%CI) Harmful (preventable adverse events): – n/N (%) Rate/1000 patient days (95%CI) Non-preventable adverse events: n/N (%) Rate/1000 patient days (95%CI)	245/1532 (*16%*) 35.8 (26.9 – 47.7) 164/1532 (*10.7%*) 22.0 (15.1 – 32.1) 81/1532 (*5.3%*) 12.9 (8.9 – 18.6) 31/1532 (*2%*) 5.2(3.1 – 8.8)	- - - - - - - -	259/1574 (*16.5%*) 41.2(31.2 – 54.5) 139/1574 (*8.8%*) 20.0 (13.2 – 30.2) 120/1574 (*7.6%*) 20.7 (15.3 – 28.1) 72/1574 (*4.5%*) 12.6(8.9 – 17.9)	 *p=0.21* *p=0.50* *p=0.01* *p=0.003*
Kottke et al., 2016	Coronary Heart Disease: Composite Score (Rates of patients meeting composite goals for CHD (blood pressure <140/90 mmHg, low-density lipoprotein cholesterol level < 100 mg/dl, tobacco-free, and using aspirin unless contraindicated)) – n/N (%) Coronary Heart Disease: Aspirin compliance – n/N (%) Diabetes: Aspirin compliance – n/N (%) Diabetes: Composite score Proport to diabetic patients (meeting CHD goal plus haemoglobin A_{1c} concentration <8%) – n/N (%) Proportion of patients satisfied or very satisfied with preventive services received – n/N (%) Providers satisfied or very satisfied with preventive services – n/N (%)	*317*/529 (59.9%) *516*/529 (97.5%) *497*/509 (97.6%) *231*/509 (45.4%) *296*/320 (92.4%) *152*/205 (74.3%)	- - - - - -	*206*/511 (40.3%) *333*/511 (65.2%) *284*/485 (58.6%) *119*/485 (24.5%) *362*/455 (79.6%) *137*/231 (59.5%)	*<0.0001* *<0.0001* *<0.0001* *<0.0001* *Not significant* *p=0.0017*
Lick et al., 2011	Survival to hospital discharge of all patients after out-of-hospital cardiac arrest – n/N (%)	48/247 (19%)	-	9/106 (8.5%)	*p=0.011*
Loh et al., 2017	-	-	-	-	-
McGrath et al., 2019	-	-	-	-	-
McKetta et al., 2016	-	-	-	-	-

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Moran et al., 2018	Care processes in hospitals with consistent submissions (patients with ISS ≥ 9):				
	Seen by consultant in ED, year-n/N (%)	16/17 – 10,943/19,197 (63%) 15/16 – 9,876/18,151 (61%) 14/15 – 8,963/16,414 (60%) 13/14 – 8,103/14,793 (60%)	12/13 – 6,169/11,708 (58%) 11/12 – 4,250/9679 (47%)	10/11–3,183/8626 (39.3%) 09/10–2,103/6957 (32%) 08/09–1,504/5338 (29%)	*Not reported*
	Intubated in ED, n (%)	2016/17 – 1,917 (11%) 2015/16 – 1,959 (12%) 2014/15 – 1,845 (12.4%) 2013/14 – 1,778 (13.2%)	2012/13 – 1,460 (13.7%) 2011/12 – 1,198 (13.3%)	2010/11 – 1,098 (13.6%) 2009/10 – 918 (13.6%) 2008/09 – 701 (13.6%)	*Not reported*
	Treated at MTC, n (%)	2016/17 – 14,247 (82%) 2015/16 – 13,279 (82%) 2014/15 – 11,873 (80%) 2013/14 – 10,790 (80%)	2012/13 – 8,212 (77%) 2011/12 – 6,750 (75%)	2010/11 – 6,113 (75%) 2009/10 – 5,058 (75%) 2008/09 – 3,757 (73%)	*Not reported*
	Blood given within 6h, n (%)	2016/17 – 423 (2.2%) 2015/16 – 470 (2.6%) 2014/15 – 405 (2.5%) 2013/14 – 391 (2.6%)	2012/13 – 372 (3.2%) 2011/12 – 259 (2.7%)	2010/11 – 283 (3.3%) 2009/10 – 270 (3.9%) 2008/09 – 118 (2.2%)	*Not reported*
	TXA if blood given, n (%)	2016/17 – 382 (90%) 2015/16 – 426 (91%) 2014/15 – 365 (90%) 2013/14 – 323 (83%)	2012/13 – 236 (63%) 2011/12 – 60 (23%)	2010/11 – 7 (2.5%) 2009/10 – 0 (0%) 2008/09 – 0 (0%)	*Not reported*
	Survival at discharge, n (%)	2016/17 – 17,451 (91%) 2015/16 – 16,424 (91%) 2014/15 – 14,878 (91%) 2013/14 – 13,388 (91%)	2012/13 – 10,568 (90%) 2011/12 – 8,808 (91%)	2010/11 – 7,895 (92%) 2009/10 – 6,313 (91%) 2008/09 – 4,891 (92%)	*Not reported*
	Time to death, median (IQR)	2016/17 – 8 (4-14) 2015/16 – 8 (4-14) 2014/15 – 8 (4-14) 2013/14 – 8 (4-13)	2012/13 – 7 (4-13) 2011/12 – 8 (4-13)	2010/11 – 8 (4-13) 2009/10 – 8 (4-14) 2008/09 – 8 (5-14)	*Not reported*
	Care process in all hospitals (patients with ISS ≥ 9):				
	Intubated by Dr prehospital, n (%)	2016/17 – 44 (0.1%) 2015/16 – 73 (0.2%) 2014/15 – 99 (0.3%) 2013/14 – 80 (0.3%)	2012/13 – 73 (0.3%) 2011/12 – 41 (0.2%)	2010/11 – 80 (0.5%) 2009/10 – 80 (0.7%) 2008/09 – 50 (0.6%)	*Not reported*
	Seen by consultant in ED, n (%)	2016/17 – 18,797 (46.2%) 2015/16 – 17,691 (45.3%) 2014/15 – 16,111 (46.3%) 2013/14 – 14,406 (46.3%)	2012/13 – 11,531 (43.7%) 2011/12 – 7,601 (34.6%)	2010/11 – 5,217 (30.5%) 2009/10 – 3,218 (27.3%) 2008/09 – 2,188 (25%)	*Not reported*

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	Seen by consultant in ED if ISS >15, n (%)	2016/17 – 9,412 (56.8%) 2015/16 – 8,876 (56.4%) 2014/15 – 7,942 (57.8%) 2013/14 – 7,044 (57.7%)	2012/13 – 5,552 (54.8%) 2011/12 – 3,825 (43.7%)	2010/11 – 2,712 (38.2%) 2009/10 – 1,713 (34.6%) 2008/09 – 1,136 (31.9%)	*Not reported*
	Seen by consultant in ED if GCS <13, n (%)	2016/17 – 2,724 (76%) 2015/16 – 2,755 (74.8%) 2014/15 – 2,558 (74.6%) 2013/14 – 2,384 (75.4%)	2012/13 – 1,981 (72.9%) 2011/12 – 1,338 (62%)	2010/11 – 1,027 (58%) 2009/10 – 664 (52.2%) 2008/09 – 459 (47.4%)	*Not reported*
	Intubated in ED, n (%)	2016/17 – 2,929 (7.2%) 2015/16 – 2,976 (7.6%) 2014/15 – 2,850 (8.2%) 2013/14 – 2,700 (8.7%)	2012/13 – 2,386 (9%) 2011/12 – 1,898 (8.6%)	2010/11 – 1,639 (9.6%) 2009/10 – 1,248 (10.6%) 2008/09 – 951 (10.9%)	*Not reported*
	Survival at discharge, year-n/N (%)	16/17–40407/44059 (91.7%) 15/16–38733/42371 (91.4%) 14/15–34558/37725 (91.6%) 13/14–30808/33647 (91.6%)	12/13–25829/28239 (91.5%) 11/12–21385/23211 (92.1%)	10/11–16535/17956 (92.1%) 09/10–11129/12123 (91.8%) 08/09–8245/8903 (92.6%)	*Not reported*
	TXA given, year-n/N (%)	16/17–3,041/44069 (6.9%) 15/16–3,633/42371 (8.6%) 14/15–3,092/37725 (8.2%) 13/14–2,511/33647 (7.5%)	12/13–1217/28239 (4.3%) 11/12–304/23211 (1.3%)	10/11–24/17956 (0.1%) 09/10–1/12123 (0%) 08/09–2/8903 (0%)	*Not reported*
	Blood given within 6h, year-n/N (%)	16/17–672/44069 (1.5%) 15/16–810/42371 (1.9%) 14/15–714/37725 (1.9%) 13/14–633/33647 (1.9%)	12/13–639/28239 (2.3%) 11/12–396/23211 (1.7%)	10/11–374/17956 (2.1%) 09/10–333/12123 (2.7%) 08/09–174/8903 (2%)	*Not reported*
	TXA and blood given within 6h, year-n/N (%)	16/17–601/44069 (89.4%) 15/16–717/42371 (88.5%) 14/15–616/37725 (86.3%) 13/14–485/33647 (76.6%)	12/13–394/28239 (61.7%) 11/12–89/23211 (22.5%)	10/11–7/17956 (1.9%) 09/10–1/12123 (0.3%) 08/09–1/8903 (0.6%)	*Not reported*
	Time to death within 30 days, year-median (IQR), N	16/17–8 (4-14), 44069 15/16–8 (4-14), 42371 14/15–8 (4-14), 37725 13/14–8 (4-13), 33647	12/13–7 (4-13), 28239 11/12–8 (4-13), 23211	10/11–8 (4-13), 17956 09/10–8 (4-14), 12123 08/09–8 (5-14), 8903	*Not reported*
New et al., 2016	90-day readmissions – n/N (%)	102/*567* (18%)	-	94/*470* (20%)	*p=0.3000*
	Complications – n/N (%)	70/*583* (12%)	-	47/*470* (10%)	*p=0.070*
Rateb et al., 2011	Percentage of satisfied customers with:				
	Medical services - n/N (%)	*216*/251 (86%)	-	*22*/63 (34.3%)	*P*<0.001
	Housekeeping - n/N (%)	*225*/251 (89.7%)	-	*21*/63 (34%)	*P*<0.001

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	Staff communication - n/N (%) Accessibility - n/N (%)	*231*/251 (91.9%) *215*/251 (85.8%)	- -	*18*/63 (31.3%) *19*/63 (30%)	*P*<0.001 *P*<0.001
Rustagi et al., 2016	Proportion of HIV-positive pregnant women who received antiretroviral medications – n/N (%): Cote d'Ivoire Kenya Mozambique Mean proportion of HIV-exposed infants who received an HIV CPR screening test by 6 or 8 weeks of age: Cote d'Ivoire Kenya Mozambique	Overall - *13*/17 (77.7%) 100%, N = 5 73.4%, N = 6 63.5%, N = 6 Overall mean=46.1%, N=18 51.2%, N = 6 41.5%, N = 6 46.3%, N = 6	- - - - - - - -	Overall - *12*/18 (66.45%) 79.2%, N = 6 52.5%, N = 6 67.6%, N = 6 Overall mean=34.5%, N = 18 36.0%, N = 6 44.5%, N = 6 23.35%, N = 6	*p*=0.36 *p*=0.62 *p*=0.02 *p*=0.23 *p*=0.25 *p*=0.57 *p*=0.88 *p*=0.04
Ryan et al., 2006	Severity of Alcohol Dependence Questionnaire (SADQ) score – n/N (%): **Mild/Moderate:** Planned discharge Unplanned discharge **Severe:** Planned discharge Unplanned discharge Housing – n/N (%): **Stable:** Planned discharge Unplanned discharge **Unstable:** Planned discharge Unplanned discharge	 721/977 (73.8%) 256/977 (26.2%) 1965/*2,748* (71.5%) 785/*2,754* (28.5%) 2340/3,233 (72.4%) 893/3,233 (27.6%) 390/572 (68.2%) 182/572 (31.8%)	 - - - - - - - -	 124/191 (64.9%) 67/191 (35.1%) 102/*164* (62.0%) 65/*171* (38.0%) 787/1,168 (67.4%) 381/1,168 (32.6%) 243/395 (61.5%) 152/395 (38.5%)	 *P<0.012* *P<0.008* *P<0.001* *P<0.032*
Shultz et al., 2015	-	-	-	-	-
Srinivasan et al., 2017	Rate of NG hydration – n/N (%) **Primary outcome measure** NG tube placed for hydration – n/N (%) **Rate of NG complications** Aspiration- n/N (%) Death - n/N (%) Epistaxis - n/N (%) Displacement/removal - n/N (%)	53/91 (58%) 53 (58%) n = 53 0/53 (0%) 0/53 (0%) 0/53 (0%) 17/53 (32%)	53/91 (58%)	0/221 (0%) 0 (0%) 0/221 (0%) 0/221 (0%) 0/221 (0%) 0/221 (0%)	*Not reported* -

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Tetuan et al., 2017[22]	-	-	-	-	-

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Table 4b – Numbers and numerical values – Patient outcomes: Studies with Concurrent Control Designs

Study	Outcomes measures	Intervention	Control 1	Control 2	Control 3	P-values
Allaudeen et al., 2017	-	-	-	-	-	-
Huntington et al., 2012	Percentage of births delivered in health facilities per year	72%, n=7,017	46%, n=Not provided	33%, n=Not provided	28%, n=Not provided	-
	Number of maternal deaths per year – n/N (%) [showing best three of five controls]	18/*15,789* (0.114%)	9, n=Not provided	11, n=Not provided	16, n=Not provided	-
McGrath et al., 2019	-	-	-	-	-	-
New et al., 2016	90-day readmissions – n/N (%)	102/*567* (18%)	55/*306* (18%)	-	-	*p=0.3000*
	Complications – n/N (%)	70/*583* (12%)	32/*320* (10%)	-	-	*p=0.070*
Rothemich et al., 2010	-	-	-	-	-	-
Rustagi et al., 2016	Mean proportion of HIV-positive pregnant women who received antiretroviral medications:	Overall mean=77.7%, N = 17	Overall mean=65.9%, n=17	-	-	-
	Cote d'Ivoire	100%, N = 5	100%, n=5	-	-	-
	Kenya	73.4%, N = 6	38.5%, n=6	-	-	-
	Mozambique	63.5%, N = 6	64.9%, n=6	-	-	-
	Mean proportion of HIV-exposed infants who received an HIV CPR screening test by 6 or 8 weeks of age:	Overall mean=46.1%, N = 17	Overall mean=32.0%, N = 17	-	-	-
	Cote d'Ivoire	51.2%, N = 5	42.6%, N = 6	-	-	-
	Kenya	41.5%, N = 6	19.2%, N = 5	-	-	-
	Mozambique	46.3%, N = 6	32.1%, N = 6	-	-	-
Shultz et al., 2015	Number of patients receiving Tdap vaccination-n/N (%):					
	Follow-up	6,978/14,748 (47.3%)	4 343/14,395 (30.2%)	-	-	*p<0.001*
	Intervention year	12,267/22,565 (54.4%)	3 806/17,043 (22.3%)			
	Base-line	3,976/25,584 (15.5%)	2 623/18,587 (14.1%)			
	Number of patients receiving flu vaccination-n/N (%):					
	Follow-up	4 417/14,748 (30.0%)	6 743/14,395 (46.8%)	-	-	*p<0.001*
	Intervention year	9 301/22,565 (41.2%)	8 197/17,043 (48.1%)			
	Base-line	6 867/25,584 (26.8%)	6 738/18,587 (36.3%)			

Supplementary file 2- Data extraction tables

Table 5a – Numbers and numerical values – Service, Resource or Cost outcomes: Studies with Before, During & After Designs

Study	Outcomes measures	After	During	Before	P-values
Afsar-manesh et al., 2016	-	-	-	-	-
Allaudeen et al., 2017	ED Length of Stay for medicine admissions, hrs- mean (SD) N Year 1 Year 2 Year 3	7.2 [n or N not reported] 7.9 7.1 6.4	-	8.7 [n or N not reported]	*P<0.001*
Anderson et al., 2017	Hospital LOS in days – mean, median (SD) N Time to surgery in hours – mean, median (SD) N 30-day all-cause readmissions – n/N (%) Disposition on discharge- n/N (%): Home with or without home healthcare Skilled nursing facility or nursing home Died Other Follow-up appointment scheduled before discharge – n/N (%): PCP (Internal or external to system) Metabolic Bone Clinic Orthopaedics Clinic	5.5, 5.0 (SD 2.22) N = 117 26.5, 22.3 (SD 17.5) N = 117 3/117 (2.7%) 19/117 (16%) 93/117 (79%) 0/117 (05) 5/117 (5%) 33/117 (28%) 62/117 (53%) 109/117 (93%)	- - - - - - - - - -	6.4, 5.0 (SD 4.87) N = 154 29.0, 22.5 (SD 24.9) N = 154 5/154 (3.2%) 33/154 (21%) 105/154 (68%) 1/154 (1%) 15/154 (10%) 23/154 (15%) 5/154 (3%) 126/154 (82%)	*p=0.004* *p=0.168* *p=0.520* *p=0.244* *p=0.244* *p=0.244* *p=0.244* *p=0.006* *p<0.001* *p=0.005*
Bell et al., 2017	Referral rates for cessation service overall – Incidence Rate Ratio (95% CI)	2.47 (2.16 – 2.81)	-	-	-
Bhatt et al., 2014	Operating Room (OR) Turnover Time (TT) Incidence of turnover time greater than or equal to 30 minutes – n/N (%)	mean=23m35s (SD=5m52s), n=17 (in Orthopaedic and vascular surgery only) *2*/17 (11.7%)	- -	mean=38m51s, (SD=14m39s), n=13 (Orthopaedic and vascular surgery only) *9*/13 (69.2%)	*p*< 0.001 *Not reported*
Bhutani et al., 2006	Use of hospital-based intensive phototherapy – n/N (%) Use of exchange transfusion Never events (TSB level greater than 30mg/dl)	156/11,995 (1.3%) 1(1 in 11,995 well babies) 0	159/6,395 (2.49%) 2(1 in 3,198 well babies) 0	446/8,186 (5.44%) 5(1 in 1,637 well babies) 0	- - -

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	Close calls (TSB level greater than or equal to 25mg/dl)	1 in 15,000	-	1 in 625	-
Bowen et al., 2016	Transmission error rates (of stroke alerts) via the pager system – n/N (%): ED NRR CR	 *4*/88 (5.1%) *17*/88 (18.8%) *1*/88 (1.1%)		 *30*/75 (40.0%) *17*/75 (22.7%) *9*/75 (12.0%)	 *p=0.0001* *p=0.004* *p=0.208*
Bradley et al., 2011	Antenatal care coverage – n/N (%)	140/140 (100%) β = 41.4, R^2 = 0.55	-	56/140 (40%)	*P<0.002*
	Skilled birth attendant coverage – n/N (%)	14/140 (10%) β = 2.6, R^2 = 0.50	-	7/140 (5%)	*p=0.015*
	Antenatal care HIV testing coverage	119/140 (85%) β = 26.1, R^2 = 0.54	-	70/140 (50%)	*p<0.001*
	Health post and health centre HIV testing coverage	β = 2.7, R^2 = 0.39	-	-	*p<0.001*
	Average outpatient visit at health centres	β = 0.4, R^2 = 0.65 N= 10 health centres	-	-	*p=0.276*
Catchpole et al., 2014	Number of flow disruptions in Computed tomography (CT): High level trauma	 mean=18.5 (SD=18.6, Range=1-50), median=9.00, n=13	-	 mean=25.6 (SD=32.4, Range=1-105), median=13.5, n=14	-
	Low level trauma	mean=9.60 (SD=6.32, Range=1-27), median=8.00, n=107	-	mean=9.80 (SD=7.89, Range=1-65), median=8.00, n=72	-
	Time in the emergency department (ED) in minutes: High level trauma	 mean=123 (SD=76.1, Range=39-250), median=85, n=13	-	 mean=127 (SD=67.9, Range=38-291), median=119, n=14	-
	Low level trauma	mean=80 (SD=52.5, Range=13-335), median=70, n=107	-	mean=96 (SD=55.9, Range=18-347), median=84, n=72	-
	Length of Stay (LoS) in days: Cohort with Major Risk of Mortality	 Kruskal-Wallis test: LoS = 69 (z=-2.49), n=508 median=5	-	Kruskal-Wallis test: LoS = 74, n=510, median=8	p=0.01
	Cohort with Extreme Risk of Mortality	LoS=25, median=8	-	LoS= 33, median=8	-

Supplementary file 2- Data extraction tables

Chandrasekar et al., 2017	Reduction in average length of stay for AKI pre – post project	2.6hrs (14.1%), [n or N not reported]	-	-	*p<0.0001*
Cochran et al., 2018	Median length of stay per patient in minutes	162, [n or N not reported]	-	202, [n or N not reported]	*Not reported*
	Median door-to-doctor time	13, [n or N not reported]	-	27, [n or N not reported]	*Not reported*
DeFlitch et al., 2015	Average waiting time in minutes	11 [n or N not reported]	-	66 [n or N not reported]	*p<0.0001*
	Door-to-doctor time- median (MAD*), N	20 min (15), N = 56,676	-	52 min (52), N = 44,720	*p<0.0001*
	Door-to-bed time- median (MAD), N	20 min (15), N = 56,676	-	225 min (172), N = 47,167	*p<0.0001*
	Total length of stay- median (MAD), N	3.7hr (2.9), N = 57,257	-	4.8hr (3.5), N = 46,775	*p<0.0001*
	Length of stay for - median (MAD), N:				
	Discharged	3.0 hr (2.2), N = 43,527	-	4.0 hr (2.6), N = 35,628	*p<0.0001*
	Hospitalized	7.1 hr (4.1), n = 10,353	-	9.2 hr (5.8), N = 9,109	*p<0.0001*
	Observed	11.2 hr (8.2), N = 2,565	-	20.5 hr (9.0), N = 1,715	*p<0.0001*
	Same day care	5.8 hr (3.4), N = 654	-	7.6 hr (5.7), N = 323	*p<0.0001*
	Annual ED visits	57,257 (% change = 22)	-	46,775	*p<0.0001*
	Number of ED beds	47 (% change = 21)	-	39	*p<0.0001*
	Ratio of visits to ED beds	1218 (% change = 2)	-	1199	*p<0.0001*
	Number of hospital beds	484 (% change = -3)	-	500	*p<0.0001*
	RN hr/day	398 (% change = 18)	-	328	*p<0.0001*
	*Median Absolute Deviation (MAD)				
Dennerlein et al., 2017	All injuries – n/N (%)	388/2131 (18.2%)	-	448/2149 (20.8%)	-
	Body part affected - Neck/Shoulder pain:				
	Count – n/N (%)	43/2131 (2.0%)	-	64/2149 (3%)	*p<0.05*
	Rate/100FTEs (95% CI)	2.0 (1.5 – 2.7)	-	3.0 (2.3 – 3.8)	
	Rate Ratio (95% CI)	0.678 (0.46 – 1.00)			
	Cause of injury - Lifting/exertion injuries				
	Count – n/N (%)	174/2131 (8.1%)	-	239/2149 (11.1%)	*p<0.05*
	Rate/100FTEs (95% CI)	8.2 (7.0 – 9.5)	-	11.1 (9.8 – 12.6)	
	Rate Ratio (95% CI)	0.73 (0.60 – 0.89)			
	Nature of injury - Pain and inflammation				
	Count – n/N (%)	119/2131 (5.6%)	-	153/2149 (7.1%)	*p<0.05*
	Rate/100FTEs (95% CI)	5.6 (4.7 – 6.7)	-	7.1 (6.1-8.3)	
	Rate Ratio (95% CI)	0.78 (0.62 – 1.00)			
Gupta et al., 2018	Median patient arrival time (time of day)	8:45AM, N = 28	-	12:43PM, N = 36	*Not reported*
	Overall median delay from admission to chemotherapy (hrs)	3.2hrs, N = 28	-	6.2hrs, N = 36	*Not reported*

Supplementary file 2- Data extraction tables

Hathout et al., 2013	Time from referral to sleep study	Median = 125 days, [n or N not reported]	-	Median=600 days	-
	Days to treatment starting after prescription generated	21 days	-	90 days	-
	Wait for treatment after study	21 days	-	180 days	-
	Annual studies	4,289	-	1,347	
Heymann et al., 2004	Per-visit antibiotic purchasing for influenza visits	58.1 per 1000 visits	-	79.2 per 1000 visits	*p<0.0001*
Hultman et al. 2016	OR Time in minutes – mean (SD), N Perioperative Time in minutes - mean (SD), N Length of stay in days – mean (SD), N	606 (SD 146), N = 46 58 (17), N = 46 5.2 (2.3), N = 46	652 (SD 196), N = 27 65 (16), N = 27 5.6 (1.9), N = 27	715 (SD 168), N = 39 73 (16), N = 39 6.3 (1.6), N = 39	*p<0.01* *p<0.01* *p<0.01*
	Physician revenue/minute	US $7.59	-	US $6.28	*p = 0.02*
	hospital revenue/minute	US $25.11	-	US $21.84	*Not significant*
Huntington et al., 2012	Percentage of births delivered in health facilities per year	72%, [n or N not reported]	35%, [n or N not reported]	28%, [n or N not reported]	-
	Volume of blood supplies received (as a proxy indicator for improvements in availability of essential medical products for maternal health services)	983 units	355 units	36 units	-
Hwang et al., 2017	Proportion of Out-of-Hospital cardiac arrest patients receiving all CPR delivery enhancements	*24*/282 (8.5%)	*3*/117 (2.6%)	*1*/182 (0.5%)	*P<0.0001*
	Percentage of bystander CPRs without dispatcher assistance	*78*/282 (27.7%)	*32*/117 (27.4%)	*24*/182 (13.2%)	*Not reported*
	Proportion of no documented arrest rhythm by EMS	*0*/282 (0.0%)	*4*/117 (3.4%)	*11*/182 (6.0%)	*p=0.004*
	Percentage of ACLS under capnography monitoring	*175*/282 (62.2%)	*64*/117 (55.1%)	*75*/182 (41.4%)	*p=0.008*
	Percentage of extracorporeal CPR	*29*/282 (10.5%)	*9*/117 (7.7%)	3/182 (1.4%)	*p=0.052*
	Percentage of successful therapeutic hypothermia in coma patients	*97*/282 (34.4%)	*8*/117 (6.5%)	*7*/182 (3.7%)	*p<0.001*
		245/282 (87.1%)	*67*/117 (57.1%)	*112*/182 (61.5%)	*p=0.005*

Supplementary file 2- Data extraction tables

	Immediate coronary angiography for cases of presumed cardiac aetiology Number of patients who were admitted to the ICU	 101/282 (35.8%)	 31/117 (26.5%)	 29/182 (15.9%)	 *p<0.001*
Kane et al., 2019	Average hospital occupancy rate Average in-patient length of stay for department of medicine – days Time from request for admission bed till patient departs from emergency department at 92% occupancy - hrs	92% [n or N not reported] 5.3 [n or N not reported] 6.3 [n or N not reported]	- 5.5 [n or N not reported] -	85% [n or N not reported] 5.7 [n or N not reported] 9.7 [n or N not reported]	*Not reported* *Not reported* *Not reported*
Khan et al., 2018	-	-	-	-	-
Kottke et al., 2016	-	-	-	-	-
Lick et al., 2011	Interval from 911 to advanced life support at the scene in minutes – mean (SD) N Bystander cardiopulmonary resuscitation-n/N (%) Impedance threshold device use – n/N (%) In-hospital treatment of cardiac arrest patients who survived to hospital admission-n/N (%): In-hospital hypothermia Cardiac catheterization Implantable cardiac Defibrillator placed	7.2 (SD 3.6) N=247 *72*/247 (29%) *160*/247 (64.8%) *44*/95 (46%) *45*/95 (47%) *24*/95 (25%)	- - - - - -	7.5 (SD 3.5) N=106 *21*/106 (20%) *9*/106 (8.5%) 0/37 (0%) *8*/37 (22%) *5*/37 (14%)	*p=0.556* *p=0.86* - - *p<0.001* *p=0.17*
Loh et al., 2017	Number of intraocular (IOL) lens errors-n/N (%) Time between two IOL incidents Number of intraocular lens near miss error Intraocular lens implant error rates	10/39,390 (0.025%) 56 days 140/39,390 (0.36%) 2.54 per 10,000 cases N=39,390	1/7,475 (0.013%) 385 days 9/7,475 (0.12%) 1.32 per 10,000 cases, N=7,475	3/6,111 (0.049%) 35 days 36/6,111 (0.59%) 4.91 per 10,000 cases, N=6,111	- - - *Not stated*

Supplementary file 2- Data extraction tables

McGrath et al. 2019	Time required to obtain and record vital signs in seconds - mean	128.9 [n or N not reported] (t = 7.2416, df = 159.12)	-	178.8	*p<0.0001*
	Monitoring system utilization – mean (Std Err.), N:				***Values for RRs***
	Monitored hours/patient day	19.57 (0.18), N = 71	-	17.26 (0.58), N = 71	*p<0.0001*
	Monitored hours/month	19053.3 (308.9), N= 71	-	15931.25 (342.88), N = 71	*p<0.0001*
	Frequency of vital sign measurement – mean (Std. Err), N:				
	SpO2	6.7(0.026), N= 71	-	6.33(0.026), N = 71	*p<0.0001*
	Temperature	5.63(0.024), N= 71	-	5.81(0.025), N = 71	*p=1.000*
	Respiratory Rate	5.66(0.024), N= 71	-	6.15(0.026), N = 71	*p=0.0598*
	Pulse rate	7.49(0.028), N= 71	-	6.47(0.026), N = 71	*p=0.8820*
	Clinical Alarms - mean (Std. Err.), N				
	Clinical alarms/patient day	7.07 (0.46), N= 71	-	4.85 (1.11), N= 71	*p=0.0263*
	Short duration clinical alarms/patient day	5.5(0.3), N= 71	-	3.85(0.84), N= 71	*p=0.0695*
	Long duration clinical alarms /patient day	1.08(0.25), N= 71	-	0.79(0.23), N= 71	*p=0.0516*
	Duration of clinical alarms/patient day	93.79(9.78), N= 71	-	59.31(16.1), N= 71	*p=0.0002*
	Clinical alarms/monitored hour	0.4 (0.02), N= 71	-	0.32 (0.08), N= 71	*p=0.1090*
	Short duration clinical alarms/monitored hour	0.31(0.02), N= 71	-	0.25(0.06), N= 71	*p=0.2200*
	Long duration clinical alarms/monitored hour	0.06(0.01), N= 71	-	0.05(0.02), N= 71	*p=0.2467*
	Duration of clinical alarms/monitored hour	5.33(0.523), N= 71	-	3.89(1.1), N= 71	*p=0.0020*
	Non-clinical Alarm - mean (Std. Err.):				
	Nonclinical alarms/patient day	29.89 (2.4), N= 71	-	16.78 (2.11), N= 71	*p<0.0001*
	Short duration nonclinical alarms/patient day	22.63(1.81), N= 71	-	9.7(1.41), N= 71	*p<0.0001*
	Long duration nonclinical alarms/patient day	2.67(0.26), N= 71	-	1.45(0.26), N= 71	*p<0.0001*
	Duration of nonclinical alarms/patient day	1679.53 (185.69), N= 71	-	24357.56(1708.62), N= 71	*p<0.0001*
	Nonclinical alarms/monitored hour	6.39 (0.8), N= 71	-	3.7 (0.53), N= 71	*p<0.0001*
	Short duration nonclinical alarms/monitored hour	4.84(0.63), N= 71	-	2.14(0.34), N= 71	*p<0.0001*
	Long duration nonclinical alarms/monitored hour	0.57(0.14), N= 71	-	0.32(0.09), N= 71	*p<0.0001*
	Duration of nonclinical alarms/monitored hour	359.24(42.78), N= 71	-	5373.81(562.91), N= 71	*p<0.0001*
	Patient information present in monitoring system:				
	Last name (%)	678/678 (100%)	-	*551*/557 (98.92%)	*p=0.0083*
	First name (%)	678/678 (100%)	-	*188*/557 (33.75%)	*P<0.0001*
	Room and bed (%)	678/678 (100%)	-	*319*/557 (57.2%)	*P<0.0001*
McKetta et al., 2016	Mean turnaround time in Catheterization labs in minutes – mean (SD) N	32 (SD 12) N= 138	-	55 (SD 34) N=135	*p<0.001*
Moran et al., 2018	Care process in hospitals <u>with consistent submissions (patients with ISS ≥ 9)</u>:				
	First hospital MTC, n (%)	2016/17 – 12,513 (72%) 2015/16 – 11,468 (70%)	2012/13 – 7,078 (66%) 2011/12 – 5,496 (61%)	2010/11 – 4,813 (59%) 2009/10 – 3,885 (58%)	*Not reported*

Supplementary file 2- Data extraction tables

		2014/15 – 10,217 (69%) 2013/14 – 9,322 (69%)		2008/09 – 2,736 (53%)	
	Time to arrival, hours, median (IQR)	2016/17 – 1.7 (1.2-2.6) 2015/16 – 1.7 (1.2-2.5) 2014/15 – 1.6 (1.1-2.3) 2013/14 – 1.5 (1.1-2.3)	2012/13 – 1.3 (0.9-2) 2011/12 – 1.2 (0.8-1.8)	2010/11 – 1.2 (0.8-1.7) 2009/10 – 1.2 (0.9-1.7) 2008/09 – 1.2 (0.8-1.7)	*Not reported*
	CT at any time, n (%)	2016/17 – 13,868 (72%) 2015/16 – 12,818 (71%) 2014/15 – 11,276 (69%) 2013/14 – 9748 (66%)	2012/13 – 7371 (63%) 2011/12 – 5954 (62%)	2010/11 – 4874 (57%) 2009/10 – 3766 (54%) 2008/09 – 2690 (50%)	*Not reported*
	Time to surgery, median (IQR)	2016/17 – 22 (10.9-49) 2015/16 – 22 (11-47) 2014/15 – 21 (10-48) 2013/14 – 21 (10-48)	2012/13 – 20 (7-45) 2011/12 – 19 (6-46)	2010/11 – 18 (6-45) 2009/10 – 18 (5-46) 2008/09 – 18 (5-50)	*Not reported*
	Admitted to ICU or HDU, n (%)	2016/17 – 4595 (24%) 2015/16 – 4638 (26%) 2014/15 – 4151 (25%) 2013/14 – 3696 (25%)	2012/13 – 3101 (27%) 2011/12 – 2982 (31%)	2010/11 – 2719 (32%) 2009/10 – 2288 (33%) 2008/09 – 1656 (31%)	*Not reported*
	LOS in hospital, median (IQR)	2016/17 – 9 (5-19) 2015/16 – 9 (5-19) 2014/15 – 9 (5-19) 2013/14 – 9 (5-18)	2012/13 – 9 (5-19) 2011/12 – 9 (5-18)	2010/11 – 10 (5-19) 2009/10 – 10 (5-21) 2008/09 – 10 (5-21)	*Not reported*
	LOS in ICU/HDU, median (IQR)	2016/17 – 3 (1-8) 2015/16 – 3 (1-8) 2014/15 – 3 (1-8) 2013/14 – 3 (1-8)	2012/13 – 3 (1-9) 2011/12 – 3 (1-8)	2010/11 – 4 (2-10) 2009/10 – 4 (2-10) 2008/09 – 4 (2-10)	*Not reported*
	Care process in all hospitals:				*Not reported*
	First hospital MTC, year- n/N (%)	16/17 – 16,871/41149 (41%) 15/16 – 15,694 (40%) 14/15 – 14,139 (40.6%) 13/14 – 12,588 (40%)	12/13 – 9694 (36.8%) 11/12 – 6876 (31%)	10/11 – 5572/17092 (32.6%) 09/10 – 4055 (34%) 08/09 – 2789 (32%)	*Not reported*
	Time to arrival, median (IQR)	2016/17 – 1.8 (1.3-2.8) 2015/16 – 1.7 (1.2-2.6) 2014/15 – 1.6 (1.2-2.4) 2013/14 – 1.5 (1.1-2.2)	2012/13 – 1.4 (1-2.1) 2011/12 – 1.2 (0.8-1.8)	2010/11 – 1.2 (0.8-1.8) 2009/10 – 1.2 (0.9-1.7) 2008/09 – 1.1 (0.8-1.6)	*Not reported*
	Arrival at first hospital midnight – 8.00am, n (%)	2016/17 – 7184 (16.3%) 2015/16 – 6845 (16.2%)	2012/13 – 4388 (15.5%) 2011/12 – 3641 (15.7%)	2010/11 – 2894 (16.1%) 2009/10 – 2049 (16.9%)	*Not reported*

Supplementary file 2- Data extraction tables

		2014/15 – 5972 (15.8%) 2013/14 – 5241 (15.6%)		2008/09 – 1556 (17.5%)	
	CT at any time, n (%)	2016/17 – 28,865 (65.5%) 2015/16 – 27,059 (63.9%) 2014/15 – 23,036 (61%) 2013/14 – 19,774 (58.8%)	2012/13 – 15,626 (55%) 2011/12 – 12,313 (53%)	2010/11 – 8984 (50%) 2009/10 – 5953 (49%) 2008/09 – 4035 (45%)	*Not reported*
	Admitted direct or transfer to MTC, n (%)	2016/17 – 19,811 (48.7%) 2015/16 – 18,747 (48%) 2014/15 – 16,837 (48.3%) 2013/14 – 15,076 (48.4%)	2012/13 – 11,803 (44.8%) 2011/12 – 8893 (40.5%)	2010/11 – 7383 (43.1%) 2009/10 – 5394 (45.7%) 2008/09 – 3879 (44.7%)	*Not reported*
	Time to surgery, median (IQR)	2016/17 – 23.3 (13.6-47.3) 2015/16 – 22.5 (13.2-45.4) 2014/15 – 22.1 (12.3-46) 2013/14 – 21.5 (11.1-45.8)	2012/13 – 20.4 (8.7-44) 2011/12 – 20.5 (8.2-45.4)	2010/11 – 19.35 (6.7-44.8) 2009/10 – 19.4 (6.4-47.2) 2008/09 – 19.9 (5.8-50.5)	*Not reported*
	Admitted to ICU or HDU, n (%)	2016/17 – 7582 (17.2%) 2015/16 – 7719 (18.2%) 2014/15 – 7024 (18.6%) 2013/14 – 6347 (18.9%)	2012/13 – 5559 (19.7%) 2011/12 – 5180 (22.3%)	2010/11 – 4266 (23.8%) 2009/10 – 3090 (25.5%) 2008/09 – 2219 (24.9%)	*Not reported*
	LOS in hospital, median (IQR)	2016/17 – 10 (5-19) 2015/16 – 10 (5-19) 2014/15 – 10 (5-19) 2013/14 – 9 (5-18)	2012/13 – 9 (5-18) 2011/12 – 9 (5-18)	2010/11 – 9 (5-19) 2009/10 – 10 (5-20) 2008/09 – 10 (5-21)	*Not reported*
	LOS in ICU/HDU, median (IQR)	2016/17 – 3 (1-7) 2015/16 – 3 (1-7) 2014/15 – 3 (1-7) 2013/14 – 3 (1-7)	2012/13 – 3 (1-8) 2011/12 – 3 (1-7)	2010/11 – 4 (2-9) 2009/10 – 4 (2-9) 2008/09 – 4 (2-9)	*Not reported*
New et al., 2016	NOTECHS Mean (SD) – a measure of operating teams' non-technical skills	77.84 (SD 11.59) N= 25	-	73 (SD 7.1) N= 17	*p=0.938*
	WHO Time Out attempt – Component of WHO surgical safety checklist – n/N (%)	24/25 (96%)	-	17/17 (100%)	*p=1.000*
	WHO Time-Out complete compliance – number of cases in which all three components of Time-Out were completed – n/N (%)	9/25 (36%)	-	3/17 (18%)	*p=0.621*
	WHO Sign Out – number observed	1/25 (4%)	-	0/17 (0%)	*p=1.000*
		6.59 (SD 3.95) N= 25	-	7.85 (SD 2.69) N= 17	*p=0.098*

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	Glitch rate/hour – these are deviations from recognised processes with potential to reduce quality or speed – mean (SD) N Length of stay in days (SD)	7.7 (SD 15) N= 292	-	10.3 (SD 25) N= 224	*p=0.396*
Rateb et al., 2011	Monthly customer flows-mean (SD) N	3,334.3 (SD 1,888.6) N= 6	-	1,747.3 (SD 1,932.4) N= 6	*p*<0.001
	Average customer compliance with booking system across six centres (%)	Mean=75.8%, N=6	-	Mean=52.1%, N=6	*p*<0.001
	Mean time spent per customer cycle in minutes (SD) N	18.3 (SD 5.5) N=212	-	48.8 (SD 14.5) N=63	*p*<0.001
	Appointment delays (days) - mean	6.2 days	-	18 days	-
	Percentage of satisfied staff with:				
	Crowdedness	*101*/101 (100%)	-	*15*/36 (40.7%)	*p*<0.001
	Process flow	*100*/101 (99.2%)	-	*15*/36 (42.6%)	*p*<0.001
	General satisfaction	*100*/101 (99.1%)	-	*16*/36 (44.4%)	*p*<0.001
	Administrative process	*100*/101 (98.6%)	-	*13*/36 (37%)	*p*<0.001
	Housekeeping	*99*/101 (98.5%)	-	*12*/36 (32.4%)	*p*<0.001
	Medical process	*99*/101 (98.4%)	-	*15*/36 (40.7%)	*p*<0.001
	Financial benefit	*94*/101 (93.0%)	-	*12*/36 (33%)	*p*<0.001
Rustagi et al., 2016	Mean proportion of pregnant women tested for HIV at antenatal care visit:	Overall mean=95.9%, N=18	-	Overall mean=90.5%, N=18	*p=0.97*
	Cote d'Ivoire	100%, N=6	-	94.2%, N=6	*p=0.25*
	Kenya	96.0%, N=6	-	86.8%, N=6	*p=0.30*
	Mozambique	91.7%, N=6	-	90.6%, N=6	*p=0.91*
Ryan et al., 2006	-	-	-	-	-
Shultz et al., 2015	Number of visits per patient for Tdap and flu vaccinations- mean (SD) N: Number of patients receiving Tdap vaccination – n/N (%) Number of patients receiving flu vaccination.	2.6 (SD 2.4) N = 39,882 *26,419*/67,914 (38.9%) *26,011*/67,914 (38.3%)	2.9 (SD 2.7) N = 39,822 *27,573*/67,914 (40.6%) *30,018*/67,914 (44.2%)	3.0 (SD 2.9) N = 39,882 *10,119*/67,914 (14.9%) *20,918*/67,914 (30.8%)	*Not stated* *Not stated* -
Srinivasan et al., 2017	Have you ever used or placed an NG tube for hydration in an infant with bronchiolitis – n/N (%)				
	Physicians – YES	90/115 (78%)	-	23/114 (20%)	*p<0.001*
	Physicians – NO	25/115 (22%)	-	91/114 (80%)	*p<0.001*

Supplementary file 2- Data extraction tables

	Nurses – YES	62/97 (64%)	-	11/86 (13%)	*p<0.001*
	Nurses - NO	35/97 (36%)	-	75/86 (87%)	*p<0.001*
	What is your preference for hydration of an infant with bronchiolitis?				
	Physicians – n/N (%):				
	IV	6/115 (5%)	-	49/114 (43%)	*p<0.001*
	NG	49/115 (43%)	-	14/114 (12%)	*p<0.001*
	Either	60/115 (52%)	-	42/114 (37%)	*p<0.001*
	Nurses – n/N (%):				
	IV	28/97 (29%)	-	43/86 (50%)	*p=0.003*
	NG	9/97 (9%)	-	10/86 (12%)	*p=0.003*
	Either	59/97 (61%)	-	30/86 (35%)	*p=0.003*
	What are your concerns about using an NG tube for hydration?				
	Physicians – n/N (%):				
	NG tube may obstruct the nasal passage	24/115 (21%)	-	47/114 (41%)	*p=0.001*
	Risk of aspiration	21/115 (18%)	-	17/114 (15%)	*p=0.59*
	Accidental placement of the NG in the airway	16/115 (14%)	-	28/114 (25%)	*p=0.05*
	Parental resistance to the NG tube	73/115 (63%)	-	79/114 (69%)	*p=0.4*
	Other	23/115 (20%)	-	21/114 (18%)	*p=0.87*
	Nurses – n/N (%):				
	NG tube may obstruct the nasal passage	38/97 (39%)	-	49/86 (57%)	*p=0.02*
	Risk of aspiration	27/97 (28%)	-	36/86 (42%)	*p=0.06*
	Accidental placement of the NG in the airway	19/97 (20%)	-	8/86 (9%)	*p=0.06*
	Parental resistance to the NG tube	41/97 (51%)	-	44/86 (51%)	*p=0.24*
	Other	32/97 (33%)	-	13/86 (15%)	*p=0.006*
	Is NG an option for hydration in our hospital bronchiolitis guideline?				
	Physicians – n/N (%):				
	Yes	91/115 (79%)	-	29/114 (25%)	*p<0.001*
	No	0/115 (0%)	-	7/114 (6%)	*p<0.001*
	Can't tell	22/115 (19%)	-	77/114 (68%)	*p<0.001*
	Nurses – n/N (%):				
	Yes	71/97 (73%)	-	24/86 (28%)	*p<0.001*
	No	0/97 (0%)	-	3/86 (3%)	*p<0.001*
	Can't tell	25/97 (26%)	-	59/86 (69%)	*p<0.001*
	Is NG an option for hydration in the AAP bronchiolitis guideline?				

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	Physicians – n/N (%): Yes No Can't tell	 70/115 (61%) 2/115 (2%) 42/115 (37%)	 - - -	 48/114 (42%) 0/114 (0%) 65/114 (57%)	 *p=0.002* *p=0.002* *P=0.002*
Tetuan et al., 2017	Nurse workarounds – n/N (%)	175/1,998 (8.8%)	-	305/1,652 (18.5%)	*P*< 0.0001
	Safety Attitudes Questionnaire (SAQ) Score –mean (SD) N	4.05 (SD 0.547) N = 334	-	3.95 (SD 0.605) N = 585	*P*= 0.029
	Systems Thinking Scale (STS) score-mean (SD) N	64.90 (SD 8.5) N =334	-	63.39 (SD 9.36) N = 585	*P*= 0.013
	Medication events – n/N (%)	84/1,998 (4.2%)	-	156/1,652 (9.4%)	*p<0.001*
	Workaround with time, dose or omission error – n/N (%)	11/1,998 (6.3%)	-	13/1,652 (4.3%)	*p=0.3276*

Supplementary file 2- Data extraction tables

Table 5b – Numbers and numerical values – Service, Resource or Cost outcomes: Studies with Concurrent Control Designs

Study	Outcomes measures	Intervention	Control 1	Control 2	Control 3	P-values
Allaudeen et al., 2017	Reduction in ED length of stay for combined medicine and surgical admissions	0.7hrs (*p-0.003*), [n or N not reported]	0.0hrs (*p=0.2*), [n or N not reported]	-	-	*p=0.001*
Dennerlein et al., 2017	All injuries – n/N (%)	388/2131 (18.2%)	180/2414 (7.46%)	-	-	-
	Body part affected - Neck/Shoulder pain:					
	Count – n/N (%)	43/2131 (2.0%)	11/2414 (0.46%)	-	-	-
	Rate/100FTEs (95% CI)	2.0 (1.5 – 2.7)	0.46 (0.25 – 0.85)	-	-	-
	Cause of injury - Lifting/exertion injuries					
	Count – n/N (%)	174/2131 (8.1%)	48/2414 (1.99%)	-	-	-
	Rate/100FTEs (95% CI)	8.2 (7.0 – 9.5)	1.99 (1.50 – 2.64%)	-	-	-
	Nature of injury - Pain and inflammation					
	Count – n/N (%)	119/2131 (5.6%)	29/2414 (1.20%)	-	-	-
	Rate/100FTEs (95% CI)	5.6 (4.7 – 6.7)	1.20 (0.83 – 1.73)	-	-	-
Huntington et al., 2012	Volume of blood supplies received (as a proxy indicator for improvements in availability of essential medical projects for maternal health services)	983 units	941 units in Camarines Sur	-	-	-
	Number of women's health teams formed	871 teams	391 teams	[Other control provinces reported no data]	-	-
	Proportion of first level referral providers who completed a clinical training programme	74%, [n or N not reported]	[No data provided by control provinces]	-	-	-
	Facility-based delivery rate by province [showing best three of five controls]	72%, [n or N not reported]	46%, [n or N not reported]	34%, [n or N not reported]	33%, [n or N not reported]	-
McGrath et al., 2019	Frequency of vital sign measurement - mean (Std Err.), N:					
	SpO2	6.7(0.026), N = 71	6.24(0.027), N = 61	-	-	-
	Temperature	5.63(0.024), N = 71	5.57(0.026), N = 61	-	-	-
	Respiratory Rate	5.66(0.024), N = 71	5.83(0.026), N = 61	-	-	-
	Pulse rate	7.49(0.028), N = 71	7.06(0.029), N = 61	-	-	-
	System utilisation - mean (Std Err.), N:					
	Monitored hours/patient day	19.57(0.18), N = 71	12.98(0.58), N = 61	-	-	-

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	Monitored hours/month	19053.3(308.9), N = 71	5225.05(208.95), N = 61	-	-	-
	Clinical Alarms - mean (Std Err.), N:					
	Clinical alarms/patient day	7.07(0.46), N = 71	5.73(0.63), N = 61	-	-	-
	Short duration clinical alarms/patient day	5.5(0.3), N = 71	4.52(0.49), N = 61	-	-	-
	Long duration clinical alarms /patient day	1.08(0.25), N = 71	1.06(0.09), N = 61	-	-	-
	Duration of clinical alarms/patient day	93.79(9.78), N = 71	73.84(9.7), N = 61	-	-	-
	Clinical alarms/monitored hour	0.4(0.02), N = 71	0.5(0.07), N = 61	-	-	-
	Short duration clinical alarms/monitored hour	0.31(0.02), N = 71	04(0.06), N = 61	-	-	-
	Long duration clinical alarms/monitored hour	0.06(0.01), N = 71	0.09(0.01), N = 61	-	-	-
	Duration of clinical alarms/monitored hour	5.33(0.52), N = 71	6.47(1.22), N = 61	-	-	-
	Non-clinical Alarm - mean (Std Err.), N:					
	Nonclinical alarms/patient day	29.89(2.4), N = 71	26.34(6.38), N = 61	-	-	-
	Short duration nonclinical alarms/patient day	22.63(1.81), N = 71	14.32(1.9), N = 61	-	-	-
	Long duration nonclinical alarms/patient day	2.67(0.26), N = 71	1.58(0.2), N = 61	-	-	-
	Duration of nonclinical alarms/patient day	1679.53(185.69), N = 71	56084.88(15639.76), N = 61	-	-	-
	Nonclinical alarms/monitored hour	6.39(0.8), N = 71	1.0(0.4), N = 61	-	-	-
	Short duration nonclinical alarms/monitored hour	4.84(0.63), N = 71	0.54(0.15), N = 61	-	-	-
	Long duration nonclinical alarms/monitored hour	0.57(0.14), N = 71	0.06(0.02), N = 61	-	-	-
	Duration of nonclinical alarms/monitored hour	359.24(42.78), N = 71	2132.4(676.96), N = 61	-	-	-
New et al., 2016	NOTECHS Mean (SD) - a measure of operating teams' non-technical skills	77.84 (11.59), N = 25	78.06 (6.57), N = 16	-	-	*p=0.938*
	WHO Time Out attempt - Component of WHO surgical safety checklist – n/N (%)	24/25 (96%)	16/16 (100%)	-	-	*p=1.000*
	WHO Time-Out complete compliance - number of cases in which all three components of Time-Out were completed - n/N (%)	9/25 (36%)	10/16 (62%)	-	-	*p=0.621*

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	WHO Sign Out - number observed- n/N (%)	1/25 (4%)	1/16 (6%)	-	-	*p=1.000*
	Glitch rate/hour - these are deviations from recognised process with potential to reduce quality or speed – mean (SD), N	6.59 (SD 3.95), N = 25	7.94 (SD 4.01), N = 16	-	-	*p=0.098*
	Length of stay in days (SD), N	7.7 (SD 15), N = 292	7.6 (SD 16), N = 173	-	-	*p=0.396*
Rothemich et al.	Counselling behaviour:					
	Ask – patient was asked if you smoke	*525*/857 (61.2%)	*637*/958 (66.5%)	-	-	*p=0.45*
	Advise- patient was advised to stop	*499*/857 (58.2%)	*530*/958 (55.3%)	-	-	*p=0.39*
	In-office cessation support(unadjusted)	*349*/857 (40.7%)	*270*/958 (28.2%)	-	-	*p<0.001*
	In-office cessation support (adjusted)	*333*/857 (38.9%)	*273*/958 (28.5%)	-	-	
	Patient who had discussion	*295*/857 (34.4%)	*262*/958 (27.4%)	-	-	*p=0.001*
	Patients who had referral to quitline	*183*/857 (21.4%)	*83*/958 (8.7%)	-	-	*p<0.001*
Rustagi et al., 2016	Mean proportion of pregnant women tested for HIV at antenatal care visit:	Overall mean=95.9%, N = 18	Overall mean=93.4%, N=18	-	-	-
	Cote d'Ivoire	100%, N = 6	99.9%, N = 6	-	-	-
	Kenya	96.0%, N = 6	87.3%, N = 6	-	-	-
	Mozambique	91.7%, N = 6	92.9%, N = 6	-	-	-

Supplementary file 2- Data extraction tables

Quality assessment

Table 6: CASP questions for appraisal of a Cohort Study (possible answers for each question are: Yes, Can't Tell and No)

	Studies		1. Did the study address a clearly focused issue?	2. Was the cohort recruited in an acceptable way?	3. Was the exposure accurately measured to minimise bias?	4. Was the outcome accurately measured to minimise bias?	5. (a) Have the authors identified all important confounding factors?	5. (b) Have they taken account of the confounding factors in the design and /or analysis	6. (a) Was the follow up of subjects complete enough?	6. (b) Was the follow up of subjects long enough?	7. Do you believe the results?	8. Can the results be applied to the local population?	9. Do the results of this study fit with other available evidence?	10. What are the implications of this study for practice?
1	**Cohort**	**Afsar-manesh et al.**[1]	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y	Y
2	**Case Control**	**Allaudeen et al.**	See	Next										
3	**Cohort**	**Anderson et al.**	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y
4	**Cohort**	**Bell et al.**	Y	Y	Y	Y	Y	CT	CT	N	Y	CT	Y	Y
5	**Case Control**	**Bhatt et al.**[3]	See	Next										
6	**Case Control**	**Bhutani et al.**[4]	See	Next										
7	**Cohort**	**Bowen et al.**	Y	Y	Y	Y	CT	CT	N	N	Y	CT	Y	Y
8	**Cohort**	**Bradley et al.**[5]	Y	Y	Y	Y	CT	CT	Y	Y	Y	N	Y	Y
9	**Case Control**	**Catchpole et al.**[6]	See	Next										
10	**Cohort**	**Chandrasekar et al.**	Y	Y	Y	Y	Y	CT	CT	Y	CT	CT	CT	CT
11	**Cohort**	**Cochran et al.**	Y	Y	Y	Y	N	N	CT	Y	Y	CT	CT	Y
12	**Cohort**	**DeFlitch et al.**	Y	Y	Y	Y	Y	CT	CT	Y	Y	CT	Y	Y
13	**Cohort**	**Dennerlein et al.**[7]	Y	Y	Y	Y	CT	CT	Y	Y	Y	N	Y	Y
14	**Cohort**	**Gupta et al.**	Y	Y	Y	Y	CT	CT	CT	Y	Y	Y	Y	Y
15	**Cohort**	**Hathout et al.**[8]	Y	Y	Y	CT	Y	CT	Y	CT	Y	Y	CT	Y
16	**Cohort**	**Heymann et al.**[9]	Y	N	CT	N	N	N	CT	CT	CT	CT	CT	N
17	**Cohort**	**Hultman et al.**	Y	Y	Y	Y	Y	CT	CT	Y	Y	Y	Y	Y
18	**Cohort**	**Huntington et al.**[10]	Y	Y	N	Y	Y	Y	Y	CT	CT	N	Y	Y
19	**Cohort**	**Hwang et al.**[11]	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y
20	**Cohort**	**Kane et al.**	Y	Y	Y	Y	Y	CT	CT	CT	CT	CT	CT	CT
21	**Cohort**	**Khan et al.**	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
22	**Cohort**	**Kottke et al.**[12]	Y	Y	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y
23	**Cohort**	**Lick et al.**[13]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
24	**Cohort**	**Loh et al.**[14]	Y	Y	CT	Y	Y	Y	Y	Y	Y	N	Y	CT
25	**Case Control**	**McGrath et al.**	See	Next										
26	**Cohort**	**McKetta et al.**[15]	Y	Y	Y	Y	CT	CT	Y	CT	Y	Y	Y	Y
27	**Cohort**	**Moran et al.**	Y	Y	Y	Y	Y	CT	Y	Y	Y	Y	Y	Y
28	**Cohort**	**New et al.**[16]	CT	Y	Y	CT	N	N	Y	N	N	CT	CT	CT
29	**Cohort**	**Rateb et al.**[17]	Y	Y	Y	Y	CT	CT	CT	CT	Y	Y	Y	Y
30	**RCT**	**Rothemich et al.**[18]	See	Two	Next									
31	**RCT**	**Rustagi et al.**[19]	See	Two	Next									

Supplementary file 2- Data extraction tables

32	**Cohort**	**Ryan et al.**[20]	Y	Y	CT	CT	CT	CT	Y	Y	CT	CT	Y	Y
33	**Cohort**	**Shultz et al.**[21]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
34	**Cohort**	**Srinivasan et al.**	Y	Y	Y	Y	Y	CT	CT	N	CT	CT	CT	CT
35	**Cohort**	**Tetuan et al.**[22]	Y	Y	CT	CT	Y	CT	Y	CT	CT	Y	Y	CT

Table 7: CASP questions for appraisal of a Case Control Study (possible answers for each question are: Yes, Can't Tell and No)

		Studies	1. Did the study address a clearly focused issue?	2. Did the authors use an appropriate method to answer their question?	3. Were the cases recruited in an acceptable way?	4. Were the controls selected in an acceptable way?	5. Was the exposure accurately measured to minimise bias?	6. (a) Aside from the experimental intervention were the groups treated equally?	6. (b) Have the authors taken account of the potential confounding factors in the design and/or in their analysis?	7. Can this be applied to the local population?	8. Do the results fir with other available evidence?
2	**Case Control**	**Allaudeen et al.**	Y	Y	Y	Y	Y	Y	Y	CT	CT
5	**Case Control**	**Bhatt et al.**[3]	Y	Y	Y	N	Y	Y	Y	Y	CT
6	**Case Control**	**Bhutani et al.**[4]	Y	Y	Y	Y	Y	Y	Y	Y	Y
9	**Case Control**	**Catchpole et al.**[6]	Y	Y	Y	Y	Y	Y	Y	Y	Y
25	**Case Control**	**McGrath et al.**	Y	Y	Y	CT	Y	CT	Y	Y	Y

Table 8: CASP questions for appraisal of RCTs (possible answers for each question are: Yes, Can't Tell and No)

		Studies	1. Did the trial address a clearly focused issue?	2. Was the assignment of patients to treatments randomised?	3. Were all the patients who entered the trial properly accounted for at its conclusion?	4. Were patients, health workers and study personnel blind to treatment?	5. Were the groups similar at the start of the trial?	6. Aside fro the experimental intervention, were the groups treated equally?	7. Can the results be applied to the local population, or in your context?	8. Were all clinically important outcomes considered?	9. Are the benefits worth the harms and risks?
30	**RCT**	**Rothemich et al.**[18]	Y	Y	Y	N	Y	Y	Y		Y
31	**RCT**	**Rustagi et al.**[19]	Y	Y	Y	N	Y	Y	Y		Y

Supplementary file 3: List of studies excluded after full text review with reasons

List of studies excluded after full text review with reason for exclusion (n=72)

Summary

24 – Not a systems approach
21 – Abstracts, posters, protocols, reviews and duplicate
10 – Problem not framed in a systems context
5 – No comparator
4 – No quantitative data analysed
2 – Not been explicit about a systems approach
2 – Simulation results not applied in real-life
1 – Framed in a systems context but not evident in paper
1 – Not enough details on intervention
1 – Framework developed, not primary research
1 – About education in systems thinking

	Reference of excluded full text	Reason for exclusion
1	Dusek, J. A. *et al.* (2016) 'Patients Receiving Integrative Medicine Effectiveness Registry (PRIMIER) of the BraveNet practice-based research network: study protocol', *BMC Complementary and Alternative Medicine*, 16(1), p. 53. doi: 10.1186/s12906-016-1025-0.	Study protocol
2	Minkman, M., Ahaus, K. and Huijsman, R. (2007) 'Performance improvement based on integrated quality management models: what evidence do we have? A systematic literature review', *International Journal for Quality in Health Care*, 19(2), pp. 90–104. doi: 10.1093/intqhc/mzl071.	Literature review
3	Dhruva, A. *et al.* (2014) 'A Prospective Clinical Study of a Whole Systems Ayurvedic Intervention for Breast Cancer Survivorship', *The Journal of Alternative and Complementary Medicine*, 20(5), pp. A72–A72. doi: 10.1089/acm.2014.5189.abstract.	Abstract
4	Woods, A. (2008) 'Using lean/six sigma methodology to decrease error rate and cost of quality', *Transfusion,* Vol. 58 (supplement 2)	Poster
5	Dunbar, J. A.; O'Reilly, D. A. R.; Versace, V.; Sophy, S.; Janus, E. D (2017) Preventing progression to type 2 diabetes in women who have had gestational diabetes: Back to the drawing board?, European Association for the Study of Disease virtual meeting.	Poster
6	Boustani, M. A. (2017) Implementing the collaborative dementia care model in the real world.	Poster
7	Chandiramani, M. J.; … (2019) A multidisciplinary, multi-faceted approach to redesigning care pathways in the maternity assessment unit.	Abstract
8	P. W. Mirhosseini, C.;Hayes-Bautista, T. (2018) Depression screening: A "systems thinking" approach to address health disparities in ob/gyn practice	Abstract
9	S. J. C. Naidu, P.;Rosenthal, M.;Naik, S.;Patel, D.;Sawmynaden, V.;Cummings, S.;Jemmott, A.;Basi, M.;Hacker, K. (2019) An example of strategic collaborative working across a North Central London borough, over a 3-year period, to improve the care for people with diabetes and serious mental illness	Poster abstract
10	S. Y. Bakhai (2018) Implementation of integrated transition of care management in an academic, hospital-based safety-net primary care clinic	Presentation
11	Sherr, K. *et al.* (2014) 'Systems analysis and improvement to optimize pMTCT (SAIA): a cluster randomized trial', *Implementation science : IS*. England, 9, p. 55. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=24885976.	Protocol
12	Schnurr, P. P. *et al.* (2013) 'RESPECT-PTSD: re-engineering systems for the primary care treatment of PTSD, a randomized controlled trial', *Journal of General Internal Medicine*. United States, 28(1), pp. 32–40. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=22865017.	Not been explicit about a systems approach
13	Dietrich, A. J. *et al.* (2004) 'Re-engineering systems for the treatment of depression in primary care: cluster randomised controlled trial', *BMJ (Online)*.	Not been explicit about a systems approach
14	Muder, R. R. *et al.* (2008) 'Implementation of an industrial systems-engineering approach to reduce the incidence of methicillin-resistant Staphylococcus aureus infection', *Infection control and hospital epidemiology*. United States,	Framed in a systems context but not evident in paper

Supplementary file 3: List of studies excluded after full text review with reasons

	29(8), pp. 702–708. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med6&NEWS=N&AN=18624651.	
15	Adesina, A. A. *et al.* (2017) 'Assessing the Value of System Theoretic Process Analysis in a Pharmacovigilance Process: An Example Using Signal Management', *Pharmaceutical Medicine*. Springer International Publishing, 31(4), pp. 267–278. doi: 10.1007/s40290-017-0195-5.	No comparator
16	Alimohammadzadeh, K. *et al.* (2017) 'Assessing common medical errors in a Children's hospital NICU using failure mode and effects analysis (FMEA)', *Trauma Monthly*, 22(5), pp. 1–6. doi: 10.5812/traumamon.15845.	No comparator
17	Arrington-Sanders, R. *et al.* (2018) 'A system-level approach to improve HIV screening in an urban pediatric primary care setting', *Pediatrics*, 142(5). doi: 10.1542/peds.2018-0506.	Not a systems approach
18	Bolton, K. A. *et al.* (2017) 'The outcomes of health-promoting communities: Being active eating well initiative- A community-based obesity prevention intervention in Victoria, Australia', *International Journal of Obesity*. Nature Publishing Group, 41(7), pp. 1080–1090. doi: 10.1038/ijo.2017.73.	Not a systems approach
19	Carrougher, G. J. *et al.* (2017) 'An Intervention Bundle to Facilitate Return to Work for Burn-Injured Workers: Report from a Burn Model System Investigation', *Journal of Burn Care and Research*, 38(1), pp. e70–e78. doi: 10.1097/BCR.0000000000000410.	Not a systems approach
20	Hilton, L. G. *et al.* (2019) 'Evaluation of an Integrative Post-Traumatic Stress Disorder Treatment Program', *Journal of Alternative and Complementary Medicine*, 25(S1), pp. S147–S152. doi: 10.1089/acm.2018.0424.	Not a systems approach
21	Hung, D. Y. *et al.* (2017) 'Scaling lean in primary care: Impacts on system performance', *American Journal of Managed Care*, 23(3), pp. 161–168.	Not enough details on intervention
22	Hussein, N. A. *et al.* (2017) 'Mitigating overcrowding in emergency departments using Six Sigma and simulation: A case study in Egypt', *Operations Research for Health Care*. Elsevier Ltd, 15, pp. 1–12. doi: 10.1016/j.orhc.2017.06.003.	Simulation results not applied in real-life
23	Kazemian, P. *et al.* (2017) 'Coordinating clinic and surgery appointments to meet access service levels for elective surgery', *Journal of Biomedical Informatics*. Elsevier Inc., 66, pp. 105–115. doi: 10.1016/j.jbi.2016.11.007.	Simulation results not applied in real-life
24	Lukes, T., Schjodt, K. and Struwe, L. (2019) 'Implementation of a nursing based order set: Improved antibiotic administration times for pediatric ED patients with therapy-induced neutropenia and fever', *Journal of Pediatric Nursing*. Elsevier Inc., 46, pp. 78–82. doi: 10.1016/j.pedn.2019.02.028.	Problem not framed in systems context
25	Martin, C. M. *et al.* (2019) 'Anticipatory care in potentially preventable hospitalizations: Making data sense of complex health journeys', *Frontiers in Public Health*, 6(JAN). doi: 10.3389/fpubh.2018.00376.	No quantitative data to analyse
26	Mutale, W. *et al.* (2017) 'Application of systems thinking: 12-month postintervention evaluation of a complex health system intervention in Zambia: the case of the BHOMA', *Journal of Evaluation in Clinical Practice*, 23(2), pp. 439–452. doi: 10.1111/jep.12354.	No quantitative data to analyse
27	Myers, M. K. *et al.* (2018) 'Using knowledge translation for quality improvement: An interprofessional education intervention to improve thromboprophylaxis among medical inpatients', *Journal of Multidisciplinary Healthcare*, 11, pp. 467–472. doi: 10.2147/JMDH.S171745.	Problem not framed in systems context though they say they performed a systems analysis
28	Redwood, R. *et al.* (2018) 'Reducing unnecessary culturing: A systems approach to evaluating urine culture ordering and collection practices among nurses in two acute care settings', *Antimicrobial Resistance and Infection Control*. Antimicrobial Resistance & Infection Control, 7(1), pp. 1–8. doi: 10.1186/s13756-017-0278-9.	No quantitative data to analyse
29	Steward, D., Glass, T. F. and Ferrand, Y. B. (2017) 'Simulation-Based Design of ED Operations with Care Streams to Optimize Care Delivery and Reduce Length of Stay in the Emergency Department', *Journal of Medical Systems*. Journal of Medical Systems, 41(10). doi: 10.1007/s10916-017-0804-6.	No baseline data
30	Adaba, G. B. and Kebebew, Y. (2018) 'Improving a health information system for real-time data entries: An action research project using socio-technical systems theory', *Informatics for Health and Social Care*. Taylor & Francis, 43(2), pp. 159–171. doi: 10.1080/17538157.2017.1290638.	No comparator
31	Akhter, L. S. *et al.* (2017) 'Improving Asthma Control through Asthma Action Plans: A Quality Improvement Project at a Midwest Community Clinic', *Journal of Community Health Nursing*. Taylor & Francis, 34(3), pp. 136–146. doi: 10.1080/07370016.2017.1340764.	Not a systems approach
32	Bal, A., Ceylan, C. and Taçoğlu, C. (2017) 'Using value stream mapping and discrete event simulation to improve efficiency of emergency departments', *International Journal of Healthcare Management*, 10(3), pp. 196–206. doi: 10.1080/20479700.2017.1304323.	No comparator in practice, just assume/simulate the future state
33	Losby, J. L. *et al.* (2017) 'Safer and more appropriate opioid prescribing: a large healthcare system's comprehensive approach', *Journal of Evaluation in Clinical Practice*, 23(6), pp. 1173–1179. doi: 10.1111/jep.12756.	Not a systems approach

Supplementary file 3: List of studies excluded after full text review with reasons

34	Verbano, C., Crema, M. and Nicosia, F. (2017) 'Visual management system to improve care planning and controlling: the case of intensive care unit', *Production Planning and Control*. Taylor & Francis, 28(15), pp. 1212–1222. doi: 10.1080/09537287.2017.1358830.	Not a systems approach
35	Yusoff, N. S. M. *et al.* (2018) 'Discrete event simulation and data envelopment analysis models for selecting the best resource allocation alternative at an emergency department's green zone', *Sains Malaysiana*, 47(11), pp. 2917–2925. doi: 10.17576/jsm-2018-4711-35.	Not a systems approach, no comparator
36	Ammenwerth, E. *et al.* (2002) 'Systems analysis in healthcare: framework and example', *Methods of information in medicine*, 41, pp. 134–40.	Framework development not primary research
37	Boden, D. G. *et al.* (2016) 'Lowering levels of bed occupancy is associated with decreased inhospital mortality and improved performance on the 4-hour target in a UK District General Hospital', *Emergency Medicine Journal*, 33(2), pp. 85–90. doi: 10.1136/emermed-2014-204479.	Not framed in a systems context
38	Clark, C. *et al.* (2001) 'A Systematic Approach to Risk Managed Care Environment Improves', *Diabetes care*, 24(6), pp. 1079–1086. Available at: http://care.diabetesjournals.org/content/24/6/1079.full.pdf+html.	Not a systems approach
39	Gaupp, R., Körner, M. and Fabry, G. (2016) 'Effects of a case-based interactive e-learning course on knowledge and attitudes about patient safety: A quasi-experimental study with third-year medical students', *BMC Medical Education*. BMC Medical Education, 16(1), pp. 1–8. doi: 10.1186/s12909-016-0691-4.	About education in systems thinking
40	Gunn, J. *et al.* (2006) 'A systematic review of complex system interventions designed to increase recovery from depression in primary care', *BMC Health Services Research*, 6, pp. 1–11. doi: 10.1186/1472-6963-6-88.	Systematic review
41	Horbar, J. D. *et al.* (2004) 'Collaborative quality improvement to promote evidence based surfactant for preterm infants: A cluster randomised trial', *British Medical Journal*, 329(7473), pp. 1004–1007.	Not framed in a systems context
42	Press, A. I. N. (2005) 'A multifaceted collaborative quality improvement intervention significantly improves delivery of surfactant therapy for preterm infants', *Evidence-Based Healthcare and Public Health*, 9(3), pp. 219–220. doi: 10.1016/j.ehbc.2005.03.014.	Duplicate – same as Horbar et al (2004)
43	Jeon, Y. H. *et al.* (2012) 'Staff outcomes from the Caring for Aged Dementia Care REsident Study (CADRES): A cluster randomised trial', *International Journal of Nursing Studies*. Elsevier Ltd, 49(5), pp. 508–518. doi: 10.1016/j.ijnurstu.2011.10.020.	Not a systems approach
44	Jimmy, L. W. K. *et al.* (2009) 'Reduction in length of hospitalisation for microbial keratitis patients: A prospective study', *International Journal of Health Care Quality Assurance*, 22(7), pp. 701–708. doi: 10.1108/09526860910995038.	Problem not framed in a systems context
45	Kessels-Habraken, M. *et al.* (2010) 'Prospective risk analysis prior to retrospective incident reporting and analysis as a means to enhance incident reporting behaviour: A quasi-experimental field study', *Social Science and Medicine*. Elsevier Ltd, 70(9), pp. 1309–1316. doi: 10.1016/j.socscimed.2010.01.035.	No clear problem framed in a systems context
46	Lin, J. C. and Lee, T. T. (2016) 'Outcomes of medication administration information system for nurses', *Studies in Health Technology and Informatics*, 225(138), pp. 860–861. doi: 10.3233/978-1-61499-658-3-860.	Not a systems approach
47	Macfarlane, F. *et al.* (2013) 'Achieving and sustaining profound institutional change in healthcare: Case study using neo-institutional theory', *Social Science and Medicine*. Elsevier Ltd, 80, pp. 10–18. doi: 10.1016/j.socscimed.2013.01.005.	Not a systems approach, no quantitative results, does not aim to demonstrate effectiveness of SA
48	Mehta, A. D. *et al.* (2010) 'Poster 2: A System Redesign Approach to Improving Timeliness of New Outpatient PM&R Consults: Veterans Affairs Observational Analysis and System Redesign', *Pm&R*. Elsevier Inc., 2(9), pp. S9–S10. doi: 10.1016/j.pmrj.2010.07.033.	Poster
49	Miller, R. S. *et al.* (2010) 'Miller et al-2010-Systems initiatives reduce healthcare-associated infections.pdf', *The Journal of Trauma*, 68(1), pp. 23–31.	Not a systems approach
50	Mills, P. R., Weidmann, A. E. and Stewart, D. (2017) 'Hospital electronic prescribing system implementation impact on discharge information communication and prescribing errors: a before and after study', *European Journal of Clinical Pharmacology*. European Journal of Clinical Pharmacology, 73(10), pp. 1279–1286. doi: 10.1007/s00228-017-2274-7.	Not a systems approach
51	Moody-Thomas, S. *et al.* (2011) 'Awareness and implementation of the 2000 United States public health service tobacco dependence treatment guideline in a public hospital system', *Population Health Management*, 14(2), pp. 79–85. doi: 10.1089/pop.2010.0004.	Not a systems approach
52	Odetola, F. O. *et al.* (2016) 'An innovative framework to improve efficiency of interhospital transfer of children in respiratory failure', *Annals of the American Thoracic Society*, 13(5), pp. 671–677. doi: 10.1513/AnnalsATS.201507-401OC.	Not framed in a systems context
53	Palma, A. *et al.* (2013) 'Applying Systems Dynamics modeling to epidemiological research: an example of PSA screening', *American journal of epidemiology*, 175, pp. 1–145.	Abstract

Supplementary file 3: List of studies excluded after full text review with reasons

54	Procter, S. *et al.* (2013) 'Success and failure in integrated models of nursing for long term conditions: Multiple case studies of whole systems', *International Journal of Nursing Studies*. Elsevier Ltd, 50(5), pp. 632–643. doi: 10.1016/j.ijnurstu.2012.10.007.	Not a systems approach, no comparator
55	Rahman, O. *et al.* (2010) 'Sustained reduction of ventilator associated pneumonia-use of an innovation system process in a tertiary care centre', *Critical care clinics*, 38(12).	Abstract
56	Raupach, T. *et al.* (2014) 'Structured smoking cessation training for health professionals on cardiology wards: A prospective study', *European Journal of Preventive Cardiology*, 21(7), pp. 915–922. doi: 10.1177/2047487312462803.	Not a systems approach
57	Sethi, R. *et al.* (2017) 'A systematic multidisciplinary initiative for reducing the risk of complications in adult scoliosis surgery', *Journal of Neurosurgery: Spine*, 26(6), pp. 744–750. doi: 10.3171/2016.11.SPINE16537.	Not a systems approach
58	Sethi, R. K. *et al.* (2014) 'The Seattle spine team approach to adult deformity surgery: A systems-based approach to perioperative care and subsequent reduction in perioperative complication rates', *Spine Deformity*. Elsevier Inc, 2(2), pp. 95–103. doi: 10.1016/j.jspd.2013.12.002.	New surgical protocol, not a systems approach
59	Singh, R. *et al.* (2012) 'IT-enabled systems engineering approach to monitoring and reducing ADEs', *American Journal of Managed Care*, 18(3), pp. 169–175.	Not framed in a systems context
60	Sobolev, B. G., Sanchez, V. and Vasilakis, C. (2011) 'Systematic review of the use of computer simulation modeling of patient flow in surgical care', *Journal of Medical Systems*, 35(1), pp. 1–16. doi: 10.1007/s10916-009-9336-z.	Systematic review
61	Solberg, L. I. *et al.* (1997) 'Delivering clinical preventive services is a systems problem', *Annals of Behavioral Medicine*, 19(3), pp. 271–278. doi: 10.1007/BF02892291.	Not a systems approach, no comparator
62	Spijker A, Verhey F, Graff M, et al. Systematic care for caregivers of people with dementia in the ambulatory mental health service: Designing a multicentre, cluster, randomized, controlled trial. *BMC Geriatr*. 2009;9(1):1-14. doi:10.1186/1471-2318-9-21	Protocol
63	Vats A, Goin KH, Villarreal MC, Yilmaz T, Fortenberry JD, Keskinocak P. The impact of a lean rounding process in a pediatric intensive care unit. *Crit Care Med*. 2012;40(2):608-617. doi:10.1097/CCM.0b013e318232e2fc	Not a systems approach
64	Vergales BD, Dwyer EJ, Wilson SM, et al. NASCAR pit-stop model improves delivery room and admission efficiency and outcomes for infants <27 weeks' gestation. *Resuscitation*. 2015;92:7-13. doi:10.1016/j.resuscitation.2015.03.022	Systematic but not a systems approach
65	Warner CJ, Walsh DB, Horvath AJ, et al. Lean principles optimize on-time vascular surgery operating room starts and decrease resident work hours. *J Vasc Surg*. 2013;58(5):1417-1422. doi:10.1016/j.jvs.2013.05.007	Not framed in a systems context, a narrowed application of lean
66	Carr, H. *et al.* (2019) 'A Systems-wide approach to prevention of in-hospital newborn falls', *MCN, The American Journal of Maternal/Child Nursing*, 44(2), pp. 100–107.	Not a systems approach
67	Carayon, P. *et al.* (2017) 'Medication Safety in Two Intensive Care Units of a Community Teaching Hospital After Electronic Health Record Implementation: Sociotechnical and Human Factors Engineering Considerations', *Journal of Patient Safety*, 00(00), pp. 1–11. doi: 10.1097/PTS.0000000000000358.	Not a systems approach
68	Scuffham, P. A. *et al.* (2017) 'Evaluation of the Gold Coast Integrated Care for patients with chronic disease or high risk of hospitalisation through a non-randomised controlled clinical trial: A pilot study protocol', *BMJ Open*, 7(6). doi: 10.1136/bmjopen-2017-016776.	Protocol
69	Cumbler, E. *et al.* (2012) 'Improving stroke alert response time: Applying quality improvement methodology to the inpatient neurologic emergency', *Journal of Hospital Medicine*, 7(2), pp. 137–141. doi: 10.1002/jhm.984.	Not set in a systems context
70	Firman, N. and Radrekusa, J. (2016) 'A systems approach to improving cancer screening outcomes through quality improvement strategies', *Journal of Gastroenterology and Hepatology (Australia)*. Netherlands: Blackwell Publishing, 31, pp. 54–55. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed18&NEWS=N&AN=612984556.	Protocol
71	Lipshutz, A. *et al.* (2015) 'The effect of a comprehensive unit-based safety program on systems thinking in adult ICU providers', 43(12), p. 2015.	Abstract
72	Chrysanthaki, T., Hendy, J. and Barlow (2013) 'Stimulating whole system redesign: Lessons from an organisational analysis of the whole system demonstrator programme', *Journal of health services research & policy*, 18, pp. 47–55.	No quantitative data to analyse

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	6
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	6-7
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	6-7

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	7
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	-
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7-12
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	5,8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	7-8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	13
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	13
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	-
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	13-14
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	14
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	15
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	15

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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