Table S1. PRISMA Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist (Background, Method, Results, and Discussion)	Abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Table A2
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Methods
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Methods
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Methods
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Methods
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Methods
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Methods and Results
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Methods
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Methods

Section and Topic	Item #	Checklist item	Location where item is reported
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Methods
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Methods
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Not applicable
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Not applicable
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Methods
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Not applicable
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Results
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Results and Discussion
Study characteristics	17	Cite each included study and present its characteristics.	Results
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Table A4
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Tables 1-5
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Results
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Not applicable
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Discussion
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Not applicable
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Not applicable
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Not applicable
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion
	23b	Discuss any limitations of the evidence included in the review.	Discussion
	23c	Discuss any limitations of the review processes used.	Discussion
	23d	Discuss implications of the results for practice, policy, and future research.	Discussion

Section and Topic	Item #	Checklist item	Location where item is reported
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Methods
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Methods
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Not applicable
Competing interests	26	Declare any competing interests of review authors.	Conclusions
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Table A3

Table S2. Search Strategy

PubMed-Medline

(Total Quality Management[MH] OR Lean Healthcare[TW] OR Lean Method*[TW] OR Lean Philosophy[TW] OR Lean Management[TW] OR Toyota Production System*[TW] OR Six sigma[TW] OR Lean six sigma[TW]) AND (Simulat*[TW] OR Discrete event simul*[TW] OR System Dynamic*[TW] OR Model*[TW] OR Monte Carlo[TW]) AND (Healthcare[TW] OR Health*[TW] OR Hospital[TW] OR Clinic*[TW] OR Ward[TW] OR Medic*[TW] OR Sanatorium[TW] OR Nursing[TW]) AND (Patient[TW] OR Doctor[TW] OR Physician[TW] OR Nurse*[TW])

Cochrane Library

1   [mh Total Quality Management]

2   (Lean near Healthcare) OR (Lean near Method*) OR (Lean near Philosophy) OR (Lean near Management) OR (Toyota Production System*) OR (Six near Sigma) OR (Lean near Six Sigma*)

3   #1 OR #2

4   (Simulat*) OR (Discrete near event*) OR (System near Dynamic*) OR (Model*) OR (Monte near Carlo)

5   (Healthcare) OR (Health*) OR (Hospital) OR (Clinic*) OR (Ward) OR (Medic*) OR (Sanatorium) OR (Nursing)

6   (Patient) OR (Doctor) OR (physician) OR (Nurse*)

7   {AND #3-#6}

Ebsco-Host

Lean Healthcare OR Lean Method* OR Lean Philosophy OR Lean Management OR Toyota Production System* OR Six Sigma OR Lean Six Sigma*

AND

Simulat* OR Discrete Event* OR System Dynamic* OR Model* OR Monte Carlo

AND

Healthcare OR Health* OR Hospital OR Clinic* OR Ward OR Medic* OR Sanatorium OR Nursing

AND

Patient OR Doctor OR Physician OR Nurse*

Web of Science

Lean Healthcare OR Lean Method* OR Lean Philosophy OR Lean Management OR Toyota

Production System* OR Six Sigma OR Lean Six Sigma*

AND

Simulat* OR Discrete Event* OR System Dynamic* OR Model* OR Monte Carlo

AND

Healthcare OR Health* OR Hospital OR Clinic* OR Ward OR Medic* OR Sanatorium OR

Nursing

AND

Patient OR Doctor OR Physician OR Nurse*

Scopus

 (lean AND healthcare OR lean AND method* OR lean AND philosophy OR lean AND mana
gement OR toyota AND production AND system* OR six AND sigma OR lean AND
six AND sigma*)
AND

(simulat* OR discrete AND event* OR system AND dynamic* OR model* OR monte
AND carlo)
AND

(healthcare OR health* OR hospital OR clinic* OR ward OR medic* OR sanatorium OR nursin
g)
AND

Patient OR Doctor OR Physician OR Nurse*

Table S3. Extended summary of findings

(First Author, Year); Country	Setting; Study Design; n; Time Frame	Main Intervention	Outcomes	Summary of findings	Software; Simulation or Implementation
(Amati, 2022); Switzerland	Operating room; Case study; pre-post; 9 mo	Lean and DES	Mean changeover time for gynecological surgery (skin-to skin)	Reduced from 58 min to 41 min	Not Specified; Simulation
			Mean changeover time for general surgery (skin-to skin)	Reduced from 63 min to 48 min	
			Mean Potential savings	Reduced $1500 USD per room per day	
(Romano, 2022); Italy	ICU; Case Study; n=112	Lean and SD	Mean LOS	Reduced from 8.5 days/patient with std dev 7.5 to 7.5 days/patient with std dev 2.9.	Power Sim; Simulation
(Indrawati, 2022); Indonesia	Clinic; Case Study; n=96	Lean and DES	Mean Lead time	Reduced from 6398 sec to 3084 sec	FlexSim; Simulation
			Mean Process cycle efficiency (Output patient)	Increased from 96 patients to 143 patients	
(Bhosekar, 2021); USA	OR; Case Study; 24 mo	Lean (Just in Time) and DES	Mean Delay/Surgery	Reduced from 31.27 min to 1.47 min	Arena; Simulation
(Flanary, 2020); USA	Urology Clinic; Case Study; n=5,636	Lean Six Sigma and DES	Mean days for a new consult to be seen in the pediatric urology clinic	Reduced from 22.6 days in 15.5 days (P<0.0001)	Arena; Simulation
			Mean days for a new consult to be seen in the adult urology clinic	Reduced from 26 days to 19.7 days (P<0.0001)	

(Lokesh, 2020); India	Laboratory of Pediatric Emergency; Case Study; n=44; 1 mo	Lean Six Sigma and DES	Mean TAT of tests	Reduced from 69 min to 36 min	Arena; Simulation
(Gabriel, 2020); Brazil	ED; Case Study; 12 mo	Lean Six Sigma and DES	Mean LOS	Reduced from 2213.7 min to 461.2 min	FlexSim; Simulation
			Percentage of Patients who were completed treated	Increased from 17.2% to 95.7%	
(Noto, 2020); Italy	Ambulatory Care; Case Study; Pre-Post; n=5	Lean and SD	Mean time of the process	Reduced from 92 min to 65 min	Not Specified; Simulation
			Mean waiting time for patients to get register	Reduced from 8 min to 1 min	
(Rahul 2020); India	ED; Case Study; n=190; 1 month	Lean Six Sigma and DES	Mean waiting time	Reduced 76 min to 22 min	Arena; Simulation
(Ortiz-Barrios, 2020) Colombia	ED; Case Study; n= 16741; 15 mo	Lean, DES, and simulation, virtual modelling	Mean waiting time	Reduced from 201.6 min to 103.1 min	Minitab; Simulation
(Agnetis, 2019); Italy	Hematological Center; Case Study; n=49	Lean and DES	Mean patient lead time	Reduced from 1165.85 min to 747.40 min	Arena; Simulation
(Garza-Reyes, 2019); UK	Ambulance service; Case Study; n=850 ambulances; 1 month	Lean, simulation (Not Specified), internet-based technologies, and GPS tracking devices.	Mean ambulance cycle time	Reduced from 124.9 min to 75.8 min	ProModel; Simulation

(Al-Zain, 2018); Kuwait	Obstetric and Gynaecologi; Case Study; n=168	Lean Six Sigma and DES	Mean Waiting time for appointment patients	Reduced from 59.81 min to 19.83 min	Arena; Simulation
(Demir, 2018); UK	Department of Health; Case Study	Lean and DES	Mean surgeries per year	Increased from 5542 surgeries per year to 7682 surgeries per year	Simul8; Simulation
(Barnabè, 2018); Italy	Laboratory; Case Study; 2 days	Lean and Not Specified	Percentage Demand Satisfaction	Increased from 43.75% to 100%	Not Apply (Role Play); Simulation
(Ortiz, 2017); Colombia	Internal medicine; Case Study; Pre-Post	Lean and DES	Mean Lead time	Reduced from 9.94 days to 7.63 days	Arena; Simulation
(Ajdari, 2017); USA	ED; Case Study; Pre-Post; n=56	Lean and DES	Mean LOS	Reduced from 69.75 min to 57.43 min	Simio; Simulation
(Salam, 2016); Thailand	Medical Center; Case Study; Pre-Post	Lean and DES	Mean cycle time	Reduced from 5.81 h to 3.81 h	I-Grafx; Simulation
(Baril, 2016); Canada	Hematology–oncology clinic; Case Study; 10 mo; 2 mo of follow up	Lean, DES and business game-virtual environment	Mean Patient waiting time before treatment	Reduced from 61 min to 16 min	Arena; Simulation
(Dogan, 2016); Turkey	Rehabilitatio n, at Public Hospital; Case Study; n=625168	Lean and SD	Mean LOS	Reduced from 13,790 min to 11,558 min	Arena; Simulation
(Haddad, 2016); Lebanon	Radiology department; Case Study; n=6	Lean and DES	Mean Total patient time in the system	Reduced from 98.18 min to 15.99 min	Arena; Simulation
(Joshi, 2016); USA	ED; Case Study; n=200	Lean and DES	Mean Waiting Time	Reduced from 31 min to 8.3 min	Arena; Simulation

			Mean LOS: Patients choose to stay for test results and prescription	Reduced from 128 min to 119 min	
			Mean LOS: Patients need only prescription	Reduced from 59 min to 42 min	
(Bhat, 2016); India	Medical Record Department; Case Study; Pre-Post; n=100; 2 mo	Lean Six Sigma and Simulation (not specified)	Mean TAT	Reduced from 19 min to 8 min	Arena; Simulation
			Mean WIP inventory at the end of the day	Reduced from 40 units to 0 units	
(Rutman, 2015); USA	ED; Case Study, Pre-Post; n=98; 7 mo	Lean, In Situ Simulation and electronic medical records	Median time to see a provider	Reduced from 43 min to 7 min	Not Apply (In Situ); Simulation
			Percentage of Patients seen within 30 min	Increased from 33% to 93%	
			Mean LOS in ED	Reduced by 30 min	
(Lee, 2015); USA	Emergency care center; Case Study; n=18 726; 9 mo	Lean, machine learning, ABS, and optimization	Mean Overall LOS	Reduced from 10.59 h to 7.14 h	RealOpt; Implementation
			Mean of patients LWBS	Reduced from 301 patients to 210 patients	
			Percentage of 30-day Readmission rate	Reduced from 21.62% to 5.43%	
			Mean ED costs reductions and savings in penalties (from 2008-2012)	Reduced US $29.1 million	
(Lo, 2015); USA	Pediatric emergency department; Pre-Post; 7 mo	Lean, DES, real-time voice recognition system, electronic	Mean Discharged patients LOS	Increased from 161 min to 168 min	Dragon; Implementation
			Mean LOS	No Change (270 min)	

			charting, and EHR		
(Converso, 2015); Italy	ED; Case Study Simulation	Lean and SD	Mean residence time	Reduced from 6 days to 5 days	PowerSim; Simulation
			Mean waiting for the surgery (max)	Reduced from 450 min to 354 min	
(Lin, 2014); Singapore	Eye Clinic; Case Study	Lean Six Sigma and DES	Mean Patient waiting time	Reduced from 135.6 min to 103.5 min	FlexSim; Simulation
(Tejedor-Panchon, 2014); Spain	ED; Case Study; Pre-Post study; n=256,628; 36 mo	Lean, DES and digital technology in X-ray	Mean LOS in ED (time spent in the examination area)	Reduced from 80.4 min to 61.6 min (p<0.001)	I-Grafx; Implementation
			Mean LOS in TC	Reduced from 137.8 min to 123.8 min (p<0.05)	
			Mean LOS in MSC	Reduced from 219.7 min to 209.3 min (p=0.108)	
			Mean wait time to see a physician	Reduced from 58 min to 49.1 min (p<0.001)	
			Percentage of patients LWBS	Reduced from 2.8% to 2.0% (p<0.001)	
(Hirisatja 2014); Thailand	Out-patient surgery department; Case Study	Lean and DES	Mean TAT with an appointment	Reduced from 144.2 min to 114.5 min	Arena; Simulation
			Mean TAT without an appointment	Reduced from 178.2 min to 152.5 min	
			Mean waiting time with an appointment	Reduced from 89.2 min to 74.7 min	
			Mean waiting time without an appointment	Reduced from 120.5 min to 106.1 min	
(Bhat, 2014b); India	Health Information Department;	Lean Six Sigma and DES	Mean waiting time in the system	Reduced from 21.10 min to 1.19 min	Arena; Simulation

	Case Study; n=224		Mean patients on Queue	Reduced from 12 patients to 1 patient	
			Percentage scheduled utilization of staff	Reduced from 94% to 48%	
(Bhat, 2014a); India	Out-Patient Department, Case Study; n=56; 2 mo	Lean Six Sigma and DES	Mean cycle time and Mean Standard Deviation	Reduced from 4.27 min to 1.5 min and Std Dev reduced from 2.02 min to 0.43 min	Arena; Implementation
			Mean Waiting time in the system	Reduced from 32 min to 1 min	
(Celano, 2012); Italy	ED, Case Study	Six Sigma and DES	Percentage Cost Saving	33% expected cost saving per year	Arena; Just Simulation
			Mean Flow times for patients to be admitted in the audiology department	Reduced from 3.25 h to 1.5 h	
(Rosmulder, 2011); The Netherlands	ED; Case Study; n=1408; 24 mo	Lean and DES	Mean LOS	Reduced from 97 min to 83 min (p=0.05)	Tecnomatix; Simulation
(Mandahawi, 2010); Jordan	ED; Case Study; n=163	Six Sigma and DES	Mean patient waiting time	Reduced from 33.21 min to 12.93 min	ProModel; Simulation
			Mean LOS	Reduced from 84.49 min to 55.50 min	
(Khurma 2008); Canada	ED; Case Study; 1 month	Lean and DES	Mean waiting time in 1st shift	Reduced from 226.9 min to 4.9 min	ProModel; Simulation
			Mean waiting time in 2nd shift	Reduced from 124 min to 9.1 min	
			Mean Walking distance	Reduced from 226 feet to 95 feet	
(Yu, 2008); USA	Registration Department; Case Study; n=362; 3 mo	Lean Six Sigma and DES	Mean Waiting time	Reduced from 42.3 min to 6.55 min	Arena; Simulation

(Kim, 2007); USA	Radiation Oncology Department; Case Study; n=6 mo	Lean and simulation (not specified)	Mean steps needed to initiate radiation therapy	Reduced from 27 steps to 16 steps.	Not Specified; Simulation
			Mean Process time	Reduced from 290 min to 225 min	
			Mean waiting time of treatments initiated	Reduced from 7 days to 1 day	
(Nelson-Peterson, 2007); USA	Telemetry unit on hospital; time-series; Pre-Post; n=8; 5 mo	Lean and Not Specified	Mean Staff walking distance	Reduced from 5,818 steps to 846 steps	Not Specified; Simulation
			Mean Registered nurse lead time	Reduced from 240 min to 126 min	
			Mean Setup time (minutes for 1 cycle of care)	Reduced from 20 min to 3 min	

Note.

DES indicates Discrete Event Simulation; ABS, Agent Based Simulation; ED, Emergency Department; EHR, Electronic Medical Records; GPS, Global Positioning System; h, Hours; ICU, Intensive Care Unit; LOS, length of stay; LWBS, Patients who left without being seen; min, Minutes; Mo, Months; MSC, Medical Surgical Case; sec, Seconds; SD, System Dynamics; STD DEV, Standard Deviation; TAT, turnaround time; TOT, turnover time; WT, waiting time; OR, Operating Room; WIP, Work In Process; TC, Trauma Case; USD, United States Dollar.

Table S4. Traffic Light of the Risk of Bias Assessment

Risk of bias domains

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Nelson-Peterson, 2007	-	+	+	+	+	+	-	-
Kim, 2007	+	+	+	+	+	-	+	-
Yu, 2008	+	+	+	+	+	-	+	-
Khurma, 2008	+	+	+	+	+	-	+	-
Mandahawi, 2010	+	+	+	+	+	-	+	-
Rosmulder, 2011	+	+	-	-	+	-	+	X
Celano, 2012	+	+	+	+	+	-	+	-
Bhat, 2014a	+	+	+	+	+	-	+	-
Bhat, 2014b	+	+	+	+	+	-	+	-
Hirisatja, 2014	+	+	+	+	+	-	+	-
Tejedor-Panchon, 2014	-	+	+	+	+	+	-	-
Lin, 2014	+	+	+	+	+	-	+	-
Converso, 2015	+	+	+	+	+	-	+	-
Rutman, 2015	-	-	+	+	+	+	-	X
Lo, 2015	-	+	+	+	-	+	+	-
Lee, 2015	-	+	+	+	+	-	+	-
Haddad, 2016	+	+	+	+	+	-	+	-
Doğan, 2016	+	+	+	+	+	-	+	-
Bhat, 2016	+	+	+	+	+	+	+	+
Joshi, 2016	+	+	+	+	+	-	+	-
Baril, 2016	-	+	+	+	-	+	+	-
Salam, 2016	+	+	+	+	+	-	+	-
Ortiz-barrios, 2017	+	+	+	+	+	-	+	-
Ajdari, 2017	+	+	+	+	+	-	+	-
Demir, 2018	+	+	+	+	+	-	+	-
Barnabè, 2018	+	+	+	+	+	-	+	-
Garza-Reyes, 2019	-	+	+	+	+	+	+	-
Al-Zain, 2019	-	+	+	+	+	+	+	-
Agnetis, 2019	+	+	+	+	+	-	+	-
Rahul, 2020	+	+	+	+	+	+	+	+
Ortiz-Barrios, 2020	-	+	+	+	+	-	+	-
Noto, 2020	+	+	+	+	+	-	+	-
Gabriel, 2020	-	+	+	+	+	+	+	-
Lokesh, 2020	-	+	+	+	+	+	+	-
Flanary, 2020	+	+	+	+	+	+	+	+
Bhosekar, 2021	+	+	+	+	+	-	+	-
Indrawati, 2022	+	+	+	+	+	+	+	+
Romano, 2022	-	+	+	+	+	-	+	-
Amati, 2022	-	+	+	+	+	+	+	-

Domains:
D1: Bias due to confounding.
D2: Bias due to selection of participants.
D3: Bias in classification of interventions.
D4: Bias due to deviations from intended interventions.
D5: Bias due to missing data.
D6: Bias in measurement of outcomes.
D7: Bias in selection of the reported result.

Judgement
X Serious
- Moderate
+ Low