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Will the real relationship between lean and safety/ergonomics please stand up?

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ABSTRACT

This paper provides a review of studies containing safety and ergonomic outcomes in lean manufacturing (LM) environments over the past 40 years. The aim is to identify effects from specific LM methods on specific safety/ergonomic outcomes, to understand the relationship in greater detail. One hundred and one studies containing one hundred and seventy outcomes were identified. Thirty-seven outcomes pertained to just-in-time (JIT) production, which contained twenty-three negative, eleven neutral, and three positive safety/ergonomic outcomes. Conversely, twenty-six outcomes pertained to 5S and consisted of twenty-four positive, two negative, and no neutral outcomes. The most common negative JIT outcome was stress and mental strain, while the most common positive 5S outcome was a tie between safety performance and hazard exposure. Studies containing other methods were fewer in number with more mixed outcomes. These findings suggest that individual LM methods, especially JIT and 5S, uniquely contribute to the safety/ergonomic outcomes attributed to LM.

Practitioner summary

A systematic review of the scientific literature over the past forty years (1980–2020) regarding the relationship between lean manufacturing (LM) methods and occupational safety and ergonomics (OSE). The purpose is to conduct a complete historical analysis of safety and ergonomic outcomes from LM systems and methods. Areas for future research are identified and discussed.

1. Introduction

The Toyota Production System (TPS) originated in post-World War II (WWII) Japan, as the Toyota Motor Company had to overcome such challenges as a 10 to 1 productivity gap with American manufacturers, a small domestic market, American intervention in labor disputes, and eagerness of outside car manufacturers to establish operations in Japan (Womack et al., 1990). To withstand these adverse economic conditions, Toyota began innovating manufacturing methods that would evolve into the Toyota Production System (TPS). In 1946, what would later be known as the "lean factory layout" was born, where the factory floor was altered so that workers could operate multiple machines simultaneously; and by 1947, each worker was operating an average of two machines (Gronning, 1997). Standardized work, which established written procedures for each job and promoted worker interchangeability, came about in 1951; as did an employee suggestion system that would evolve into the Kaizen method (Gronning, 1997). The most significant Toyota innovations of this post-WWII period were the concepts of just-in-time (JIT) production and Kanban "pull" supply systems, the operational control system for JIT (Sugimori et al., 1977). Several other TPS methods evolved over time, such as Total productive maintenance (TPM), an employee-involved method of improving machine performance (Suryaprakash et al., 2020), and 5S, a method to create a cleaner and more efficient workspace (Goswami et al., 2019).

In 1973, a dispute between the Organization of Petroleum Exporting Countries (OPEC) and multinational oil companies resulted in massive increases on the price of oil (Fattouh, 2007). Referred to as the "1973 oil crisis", this event was followed by a recession where Japan's economy fell to a state of zero growth; but Toyota gained the attention of Japanese industry by posting higher earnings than other companies in the years that followed (Ohno, 1988). Toyota disseminated its JIT production management technology to other Japanese automakers in the late 1970s, and by the end of the decade all Japanese automakers had adopted JIT (Nakamura et al., 1998). By 1980, Toyota and other Japanese auto manufacturers had become so competitive using the TPS

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system that they had gained a 22.2% market share in US passenger car sales (Holweg, 2007). Japan was importing cars into the US at lower cost and higher quality than domestic cars, due mainly to this difference in production control systems (National Research Council, 1982). In response to the loss of market share, American industry became focused on how Japanese manufacturing methods could be adopted in the US. However, the TPS concept entered North America through Japanese "transplant" companies rather than through adoption by American car companies (Robertson et al., 1992), and these transplant companies outperformed American car companies in both quality and productivity, just as with native Japanese car companies (Womack et al., 1990; Krafcik, 1988).

Evaluating the reasons for the disparity, John Krafcik (1988) coined the term "lean" in his 1988 thesis at the Massachusetts Institute of Technology (MIT) to describe the TPS philosophy that was responsible for the superior performance. Description of the "lean" production process was then referenced in the books, "The Machine that Changed the World" (Womack et al., 1990) and "Lean Thinking" (Womack and Jones, 1996), which led to the mainstream establishment of "lean" as a manufacturing model (Liker and Hoseus, 2010; Alkhoraif et al., 2019). As with the TPS, the key feature of lean manufacturing (LM) is to increase business performance through the elimination of seven wastes: defects, overproduction, waiting, unnecessary transportation, excess inventory, motion, and over-processing (Ohno, 1988; Liker and Hoseus, 2010; Monden, 2011; Shingo and Dillon, 1989; Godinho Filho et al., 2017; Deshkar et al., 2018). Despite being essentially a re-branding of TPS, LM is the system that would gain worldwide adoption (Nunes et al., 2017).

Although LM is designed to be a worker-empowering system (Demeter and Matyusz, 2011), waste reduction efforts sometimes lead to shortened cycle times, which have the drawback of intensifying employee workload (Longoni et al., 2013). Evidence to the claims that LM was harmful to workers began to emerge. A landmark case would occur at the New United Motors Manufacturing, Inc. (NUMMI), a joint venture between General Motors and Toyota located in California. While NUMMI was lauded for achieving performance based on the high employee involvement afforded by LM, it was also cited in 1993 by California's Occupational Safety and Health Administration (Cal-OSHA) for high ergonomic injury rates (Adler, Goldoftas and Levine, 1997). The same authors published a study the following year attributing a poorly planned new model launch to the ergonomic hazards (Adler et al., 1998). However, the perception that LM increases efficiency at the expense of employee well-being would persist, as literature critical to LM continued to emerge (Landsbergis et al., 1999; Shoaf et al., 2004; Arezes et al., 2015).

Amid increasing concerns about safety and ergonomics, the National Institute for Occupational Safety and Health (NIOSH) released the report "The Changing Organization of Work and the Safety and Health of Working People" in 2002, stating that the effect lean and other new organizations of work on employee health was an area where future research is urgently needed (Sauter et al., 2002). The body of scientific literature that grew after NUMMI and the NIOSH report was both critical and complimentary of the effect of LM on occupational safety and ergonomics (Arezes et al., 2015; Hasle et al., 2012; Hamja et al., 2017), and the topic continues to be studied and debated to this day (Hamja et al., 2019).

To further understand this contested topic, this paper aims to examine the relationship between LM methods and safety/ergonomic outcomes for workers in a manufacturing environment. Koukoulaki (2014) found that lean methods such as JIT and standardized work cause intensification of work and are strongly associated with both mechanical and psychosocial exposure. Likewise Arezes, Dinis-Carvalho, and Alves (Arezes et al., 2015) identified associations between LM and several safety and ergonomic dimensions. Building on the existing works, the objective of this review is to investigate to a higher level of detail as to which LM methods (inputs) lead to which safety and ergonomic outcomes (outputs), by synthesizing literature containing safety and ergonomic outcomes associated with LM. The hypothesis is that LM methods, when considered individually, each have a unique influence on the safety and ergonomic outcomes resulting from the use of LM. This higher level of detail might explain the contradictory outcomes found in the literature, as the safety/ergonomic outcomes from an LM implementation could depend on the methods that are emphasized in that system.

2. Literature review method

To understand the effect of LM on occupational safety and ergonomics, a review was conducted with the goal of capturing, summarizing, and examining all safety and ergonomic outcomes related to the use of LM methods found in the literature. The research referred back to 1980, prior to worldwide adoption and 8 years before the term "lean" was introduced by Krafcik, attempting to gather all available literature on the topic. A systematic search and review was conducted based on the method proposed by Grant and Booth (2009) which consists of separate phases for search, appraisal, and synthesis; and is designed for exhaustive and comprehensive searching. Relevant articles from 1980 to 2020 were identified from five databases: Science Direct, Web of Science, Ergonomics Abstracts, PubMed, and Google Scholar. In addition, relevant articles cited in the identified manuscripts were also considered. Table 1 lists the search strings used in the article investigation. The search string "(1 AND 2 AND 3)" was disallowed by Science Direct due to limitations on the number of Boolean connectors used and was searched therefore using only strings "(1 AND 2)". Similarly, Google Scholar was also searched using only strings "(1 AND 2)" as this unexpectedly yielded fewer results than "(1 AND 2 AND 3)". For the remaining databases, all three search strings were used.

Sources not found in scholarly journals, conference papers/proceedings, and book chapters were excluded as part of the search setting. The focus of our research is on the worker in a manufacturing environment, not manufacturing support or other industries. Therefore, only LM implementations in a manufacturing setting were considered, which excluded industries such as healthcare, warehousing, and transportation. Studies containing implementations that combine safety and ergonomic improvement measures alongside LM were excluded, as the outcome would not be purely a result of lean.

The initial article search identified 72,815 documents. Titles and abstracts of these documents were screened according to the following criteria: 1) Relevance of the article to the topic of interest; 2) Full text papers published in peer-reviewed journals; and 3) Written in or translated into English. An irrelevant article was defined as any article clearly unrelated to manufacturing. For example, several articles concerning lean healthcare were found using the search terms, which were thus removed. Based on these criteria, 70,474 records were excluded. A full article screening (n = 2341) eliminated 1760 articles that lacked a stated safety or ergonomic outcome, and 131 duplicates were removed. The remaining articles (n = 349) were thoroughly reviewed in their entire content, and 248 were excluded where a cause-and-effect relationship was not established between LM and the safety/ergonomic outcome(s). The remaining articles (N = 101) are summarized in Table 2.

Table 1
Search strings used to identify articles.

Search String	Search Terms
1	"lean manufacturing" OR "lean production" OR "Toyota production"
2	"ergonomic" OR "stress" OR "health" OR "safety" OR "OSH"
3	"study" OR "experiment" OR "sectional" OR "longitudinal" OR "case study"

Table 2
Details from safety and ergonomic outcomes found in literature.

Article	Industry	Location	Meas. Method	Sample	Study Type	Lean Method	↑↓	Safety and Ergonomic Outcome
Babson (1993)	Automobile assembly	Michigan, USA	Survey & worker's compensation claims	2380 workers	Cross-sectional	Just-in-time (JIT) and Kaizen	↓	Increased intensity, high workers' compensation claims
Rinehart et al. (1994)	Automobile assembly	Ontario, Canada	Survey	2300 workers	Longitudinal	Unspecified lean methods or systems	↓	Workers viewed lean as "competitive and stressful" 83% of the time, "cooperative and helpful" 17% of the time. Pre-lean, these views were 43% and 57% respectively.
Mullarkey et al. (1995)	Electronics manufacturing	United Kingdom	Survey	32 workers	Longitudinal	JIT	↑↓	No effect on stress or work intensification.
Parker et al. (1995)	Car seat manufacturing	New Zealand	Questionnaires	38 workers	Longitudinal	General TPS implementation	↑↓	Neutral to positive health effects for workers participating in change, workload and strain increase for uninvolved workers.
Stewart and Garrahan (1995)	Automobile manufacturing	USA and United Kingdom	Questionnaires	372 workers in 4 factories	Case study	Unspecified lean methods or systems	↓	Workers perceived lean to be more demanding, both physically and mentally.
Jackson and Martin (1996)	Electronics manufacturing	United Kingdom	Survey	44 workers	Longitudinal	JIT	↑↓	JIT had no effect on psychological well-being.
Adler, Goldoftas, and Levine (1997)	Automobile assembly	California, USA	Cal-OSHA citations	4000 workers (est.)	Longitudinal	JIT and Kaizen	↓	Increase in ergonomic injuries, Cal-OSHA citations
Lewchuk and Robertson (1997)	Automobile assembly	Canada	Survey	2424 workers	Cross-sectional	JIT and Kaizen	↑↓	Of two lean plants, one had higher work intensity than traditional plants, one had lower
Parker and Sprigg (1998)	Truck chassis assembly (automotive)	Great Britain	Survey	38 workers	Longitudinal	Moving assembly line, work-in-process (WIP) reduction	↓	Increased stress, decreased perception of well-being
Lewchuk and Robertson (1999)	Automotive components	Canada	Survey	1670 workers, 16 workplaces	Cross-sectional	Unspecified lean methods or systems	↓	Workers reported faster pace and heavier workload in lean factories, compared to traditional factories
Yildirim (1999)	Tyre manufacturing	Turkey	Interviews and surveys	147 workers	Case study	Total quality management (TQM)	↑	Improvement in safety perception and accident rate after TQM implementation
Jackson and Mullarkey (2000)	Garment manufacturing	United Kingdom	Survey	556 workers	Cross-sectional	JIT	↑↓	No overall effect on mental job strain, balanced effect on job-related strain.
Godard (2001)	Multiple industries	Canada	Telephone survey	508 workers	Cross-sectional	JIT	↓	Negative effect on worker stress
Hunter (2001)	Machining and metalworking	South Carolina, USA	3D simulation, RULA, REBA	1 work cell simulation	Cross-sectional	Lean work cell	↑	The lean work cell presented less ergonomic risk compared to the job shop configuration.
Lewchuk et al. (2001)	Automobile manufacturing	United Kingdom and Canada	Survey	2639 workers	Cross-sectional	WIP reduction, pull systems, JIT	↓	Excessive workload, increased stress
Anderson-Connolly et al. (2002)	Anonymous company	USA	Survey	1000 workers	Longitudinal	Unspecified lean methods or systems	↓	Increased stress and higher work intensity
Bruno and Jordan (2002)	Automobile assembly	Illinois, USA	Survey	1000 workers	Longitudinal	Kaizen	↓	Job eliminations from Kaizen results intensified workload
Harenstam, Rydbeck, Johansson, Karlqvist, and Wiklund (2002)	Multiple industries	Sweden	Interviews	208 workers	Case study	General lean	↓	Increased workload reported in lean organizations.

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Table 2 (*continued*)

Article	Industry	Location	Meas. Method	Sample	Study Type	Lean Method	↑↓	Safety and Ergonomic Outcome
Parker (2003)	Automobile assembly	United Kingdom	Survey	368 workers	Longitudinal	WIP reduction, pull system	↓	Negative stress and psychological outcomes
Brenner et al. (2004)	Multiple industries	USA	Survey	1848 workers	Cross-sectional	Quality circles and JIT	↓	Negative effect on cumulative trauma disorders
Schouteten and Benders (2004)	Bicycle manufacturing	Netherlands	Survey	63 workers	Case study	JIT and standardized work	↑↓	Neutral findings on stress and general health, although increase in exhaustion was reported
Seppala and Klemola (2004)	Multiple industries	Finland	Interviews and questionnaires	525 workers	Cross-sectional	JIT	↓	Increase in stress, particularly for white-collar, maintenance, and material workers
Cochrane et al. (2005)	Dairy products	New Zealand	Postal survey	106 workers	Case study	Lean-based high-performance work practices (HPWP)	↑	52.8% of survey respondents agreed that the work environment was safer, 32.0% disagreed
Conti et al. (2006)	Multiple industries	United Kingdom	Interviews and questionnaires	1391 workers	Cross-sectional	Total productive maintenance (TPM), JIT, and Kaizen	↓	Negative ergonomic effects from JIT, negative stress effects from TPM, positive stress effects from Kaizen
Leroyer et al. (2006)	Automobile assembly	France	Questionnaire	80 workers	Longitudinal	TQM	↓	Negative effect on injury rate, strain, and stress
Mehri (2006)	Automobile assembly	Japan	Interviews and direct observations	75 affiliated people	Case study	Unspecified lean methods or systems	↓	High work intensity and injury rates, along with accident misreporting by the company
Velazquez, Munguia, de los Angeles Navarrete, and Zavala (2006)	Various industries; maquiladora manufacturing	Mexico	OSHA program evaluation profile (PEP)	50 workers	Case study	Unspecified lean methods or systems	↓	Multiple negative effects from lean production, including musculoskeletal symptoms.
Brown and O'Rourke (2007)	Shoe manufacturing	Guangdong, China	Surveys, direct measurements, and observations	1 company analyzed; 27 workers surveyed	Case study	Lean work-cell configuration	↓	Observation of increased worker exposure to heat, noise, chemicals, and moving machine parts. Surveyed workers reported higher stress.
Eklund and Berglund (2007)	Turbine and lift truck manufacturing	Sweden	Interviews	19 workers	Case study	Kaizen, TPM, and kanban	↓	Increase in worker stress and a higher work pace.
Grunberg et al. (2008)	Advanced technology products	USA	Questionnaires and interviews	525 workers, white & blue collar	Longitudinal	Unspecified lean methods or systems	↓	Increase in reported health problems after lean implementation
Hunter (2008)	Furniture manufacturing	Mississippi, USA	General shop floor observations	8 workers	Case study	Lean work-cell configuration	↑	Positive effect on ergonomics and general worker health
Mothersell et al. (2008)	Automobile manufacturing	Antwerp, Belgium	Company documentation and interviews	1 Company, >1000 workers est.	Longitudinal	Unspecified lean methods or systems	↑	Reduction in minor (first aid) accidents after lean implementation, despite doubling of car output per worker
Lu (2009)	Garment and electronics manufacturing	Philippines	Questionnaire	630 workers	Cross-sectional	Unspecified lean methods or systems	↓	Intensification of work resulted in stress, new forms of hazard, and occupational illnesses.
Nikolou-Walker and Lavery (2009)	Engineering	Ireland	Observations, interviews, & statistical analysis	250 workers	Cross-sectional	Unspecified lean methods or systems	↑↓	Lean improved overall safety, but a minority of workers experienced increased workload and stress
Saurin and Ferreira (2009)	Farm equipment manufacturing	Brazil	Survey	67 workers	Case study	Housekeeping (5S)	↑	Improvement in perceived safety
Womack et al. (2009)	Automobile manufacturing	USA	HAL and ACGIH TLV® assessments	112 jobs (56 lean and 56 traditional)	Cross-sectional	JIT, increased work frequency	↑↓	Workers in lean plant had higher HAL scores but lower ACGIH TLV

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Table 2 (*continued*)

Article	Industry	Location	Meas. Method	Sample	Study Type	Lean Method	↑↓	Safety and Ergonomic Outcome
								scores than traditional plant
Bernardo and Sato (2010)	Automobile manufacturing	Brazil	Interviews	40 workers	Case study	Unspecified lean methods or systems	↓	Physical and mental illnesses due to work pressure and work intensification.
Brännmark (2010)	Multiple industries	Sweden	Interviews and questionnaires	123 workers	Case study	Unspecified lean methods or systems	↑↓	Increase in workplace safety, but also an increase in stress
Wong and Richardson (2010)	Semiconductor manufacturing	Malaysia	Ergonomic assessment	61 workers	Cross-sectional	Unspecified lean methods or systems	↑↓	Lean production line had more reported job risk and eye strain than conventional line, but less reported head and neck pain
Edwards et al. (2011)	Multiple industries	Denmark	Seminars and surveys	3 cases, 130 total workers	Longitudinal	Unspecified lean methods or systems	↑	Lean implementation had a positive effect on the psychosocial working environment in 1 case, and a neutral effect in 2 cases
Bockerman, Bryson, and Ilmakunnas (2012)	Multiple industries	Finland	Empirical analysis of government data	3755 observations	Longitudinal	Lean-based high involvement management (HIM)	↑	HIM Practices are positively associated with employee well-being and lower accident rate
Enríquez-Díaz et al. (2012)	Automotive component manufacturing	Germany	Questionnaire	165 workers	Longitudinal	Chaku-Chaku	↓	Increased stress from work intensification
Shaikh et al. (2012)	Automotive (simulated)	United Kingdom	Questionnaire	12 participants	Case study	Cycle-time reduction through waste elimination	↑↓	Neutral effect on participant stress levels
Brännmark and Holden (2013)	Multiple industries	Sweden	Surveys and interviews	129 workers	Cross-sectional	Continuous improvement	↑↓	Higher worker perception of safety, but increase in stress
Rojasra and Qureshi (2013)	Injection molding	India	Expert assessment	1 company	Longitudinal	5S	↑	Safety scores improved after 5S implementation.
Sujatha and Rao (2013)	Multiple industries	India	Questionnaires	44 managers and executives	Cross-sectional	Unspecified lean methods or systems	↑	Safety and ergonomics had a positive relationship with lean program success.
Tregaskis et al. (2013)	Heavy manufacturing	United Kingdom	Company data, surveys, and interviews	58 various interviewees and 611 workers	Longitudinal	Lean-based high-performance work practices (HPWP)	↑	Safety perception and performance improved after HPWP was implemented.
Bouville and Alis (2014)	Multiple industries	France	Survey	24,486 employees	Cross-sectional	Unspecified lean methods or systems	↓	Lean practices, as a bundle, have a deleterious effect on employee-perceived health at work.
Chan et al. (2014)	Automotive assembly	China	Survey	1084 employees, 12 factories	Case study	Unspecified lean methods or systems	↓	High prevalence of WMSD related injury. More than 90% of workers over 35 had reported injury.
Chiarini and Vagnoni (2014)	Multiple industries	Italy	Questionnaire	40 workers	Multi-case study	TQM and 5S	↑	5S improvements led to workspaces that are safer and more ergonomic. Reduction of injuries was reported.
Cullinane et al. (2014))	Pharmaceutical manufacturing	Ireland	Survey	200 workers	Cross-sectional	Increased pace (resulting from various lean improvements)	↓	Increase in worker exhaustion
Gupta and Jain (2014)	Glass manufacturing	India	Direct observation	1 company	Longitudinal	Kaizen and 5S	↑	Kaizen based 5S improvements improved ergonomics and removed hazards.
Khandelwal et al. (2014)	Machinery manufacturing	India	IDEEA device	2 workers	Longitudinal	5S	↑	Less energy consumption after 5S improvements, which had led to stress.

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Table 2 (*continued*)

Article	Industry	Location	Meas. Method	Sample	Study Type	Lean Method	↑↓	Safety and Ergonomic Outcome
Pagell et al. (2014)	Multiple industries	Oregon, USA	Surveys, phone questionnaires, and government safety date.	153 facilities	Cross-sectional	JIT	↓	JIT was a significant and negative predictor of safety.
Shanmuganathan et al. (2014))	Textile manufacturing	India	Surveys and interviews	150 workers	Case study	5S	↑	Health and safety standards were improved after the introduction of 5S.
Singh and Ahuja (2014)	Boiler manufacturing	India	Company records	1 company	Case study	5S	↑	Decrease in accident severity after 5S implementation.
Hernández Lamprea et al. (2015)	Automotive components	Colombia	Surveys and direct assessments	1 company	Case study	5S	↑	Ergonomic, physical, and other hazards were greatly reduced after 5S implementation.
Kumar and Kumar (2015)	Multiple industries	India	Survey	59 industries	Case study	Unspecified lean methods or systems	↑↓	Reportable accidents, unsafe practices, and behavioral safety were not improved after lean implementation.
Mohiuddin et al. (2015)	Automotive manufacturing	Malaysia	Company safety data	1 company	Longitudinal	Unspecified lean methods or systems	↑	Company experienced a sharp drop in accident rate after lean implementation
Wan Mahmood et al. (2015)	Multiple industries	Malaysia	Questionnaire	40 managers and staff	Case study	Unspecified lean methods or systems	↑	Lean production has a positive correlation with sustainability components, including safety.
Zhang (2015)	Automobile manufacturing	China	Ethnographic research	7 factories	Case study	Unspecified lean methods or systems	↓	Lean systems resulted in intense work pace and high stress.
Abeysekera and Illankoon (2016)	Garment manufacturing	Sri Lanka	Survey	118 workers across 3 companies	Case study	5S, Kaizen	↑↓	Positive worker perception of workplace ergonomics, but negative perception of heat and noise hazards.
Alhuraish et al. (2016)	Multiple industries	France	Survey	33 (est.) lean experts	Case study	Unspecified lean methods or systems	↑↓	Hypothesis that lean had positive safety effects was rejected.
Baoet al. (2016)	Multiple industries	USA	SI, HAL, TLV®, assessments	1834 workers	Cross-sectional	Single-piece flow	↑↓	Workers using single-piece flow had higher perception of H&S and lower force requirements, but higher repetition of forceful exertions.
Hussain et al. (2016)	Textile manufacturing	Pakistan	Questionnaire	326 employees	Case study	Standardized work	↑↓	Standardized work created more stress for blue-collar workers, less for white-collar workers.
Kumar and Kumar (2016)	Multiple industries	India	Survey	62 companies	Case study	Unspecified lean methods or systems	↑	Lean has a positive impact on employee safety participation.
Manfredsson (2016)	Textile manufacturing	Sweden	Interviews, observations, & group discussions.	2 teams, 11 total workers	Case study	Unspecified lean methods or systems	↑↓	Lean was found to have increased stress in one company, but reduced stress in another.
Ramesh and Ravi (2016)	Cutting tool manufacturing	India	Questionnaire	75 workers	Case study	5S	↑	Significant relationship between 5S implementation and improved safety performance.
Resta et al. (2016)	Multiple industries	Italy	Interviews, direct observations, company documentation	Unknown sample from >300,000 workers	Case study	JIT, TQM and TPM	↑↓	JIT implementation resulted in higher safety and ergonomics, but higher stress. TQM resulted in reduced risks. TPM resulted in

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Table 2 (*continued*)

Article	Industry	Location	Meas. Method	Sample	Study Type	Lean Method	↑↓	Safety and Ergonomic Outcome
								reduced risks and reduced stress.
Srinivasan et al. (2016)	Instrumentation device manufacturing	USA	Survey	8 participants plus 5 control	Longitudinal	5S	↑	Safety climate improved after 5S implementation; remained unchanged for the control group.
Stewart et al. (2016)	Automobile manufacturing	United Kingdom and Poland	Surveys and interviews	439 workers	Case study	Unspecified lean methods or systems	↓	Increased work intensity, higher levels of physical discomfort, stress, and exhaustion after lean introduction.
Widyanti and Larutama (2016)	Aerospace manufacturing	Indonesia	Questionnaires and NASA-TLX	90 workers	Case study	Unspecified lean methods or systems	↑↓	No significant correlation between lean performance and mental workload.
Aziz et al. (2017)	Textile manufacturing	Egypt	Direct observation	2 factories	Case study	Unspecified lean methods or systems	↑	Lean implementation resulted in a reduction of heat, chemical, and ergonomic hazards.
Camuffo et al. (2017)	Tire manufacturing	Multiple countries (Europe)	Interviews and observations	32 production departments in 9 facilities	Cross-sectional	Unspecified lean methods or systems	↑	The degree of lean adoption was positively related to a reduction of accidents.
Distelhorst et al. (2017)	Apparel manufacturing (Nike)	11 developing countries	Factory audits	300 factories	Cross-sectional	Unspecified lean methods or systems	↑↓	No relationship was found between lean adoption and health and safety standards.
Håkansson et al. (2017)	Fabricated metal products	Sweden	Surveys, interviews, assessments	70 workers (est.)	Longitudinal	Kaizen, standardized work	↑	Kaizen made jobs less strenuous and improved H&S perception. Standardized work had no effect on stress level.
Huo and Boxall (2017)	Consumer-goods manufacturing	China	Survey	226 frontline managers	Case study	Unspecified lean methods or systems	↓	Lean-associated role overload was a risk to frontline managers, which relates to exhaustion.
Ramesh and Ravi (2017)	Cutting tool manufacturing	India	Questionnaire	75 workers	Case study	Unspecified lean methods or systems	↑	70.6% of workers felt that total employee involvement created a safe workplace.
Todorovic and Cupic (2017)	Rubber goods manufacturing	Serbia	Company OHS metrics	1179 workers	Case study	5S	↑	Injury frequency and severity showed downward trends after 5S implementation.
Wiengarten et al. (2017)	Multiple industries	USA	OSHA and COMPUSTAT data	3945 companies	Cross-sectional	Slack (waste) reduction	↓	Reduction in operational slack increases number of safety violations.
Fernandes et al. (2018)	Automobile manufacturing	Europe	Direct observation	1 work area	Longitudinal	5S	↑	5S implementation reduced risk of forklift-pedestrian collision by 64%.
Huo and Boxall (2018)	Transportation equipment manufacturing	China	Questionnaire	357 workers	Case study	Employee problem solving	↓	Problem solving demands from lean implementation increase exhaustion but may be mitigated by increased job resources.
Morvan and Buchmann (2018)	Automotive and aerospace manufacturing	France	Company records and worker interviews	2 companies	Cross-sectional	JIT	↓	Increase in WMSD from JIT implementation.
Nagaraj and Jeyapaul (2018)	Garment industry	Sri Lanka	Questionnaires, REBA, and CMDQ	557 workers	Case study	Lean cell design and one-piece flow	↓	Workers experienced medium ergonomic risk on most jobs, and high occurrence of pain & discomfort
Randhawa and Ahuja (2018)	Automotive parts manufacturing	India	Company safety metrics	36 manufacturing zones	Case study	5S and Kaizen	↑	Accident frequency and severity improved after 5S, improved

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Table 2 (*continued*)

Article	Industry	Location	Meas. Method	Sample	Study Type	Lean Method	↑↓	Safety and Ergonomic Outcome
								further through Kaizen.
Ratnayake and Dinosha (2018)	Apparel manufacturing	Sri Lanka	Surveys	84 workers	Cross-sectional	Lean work cell (U-shaped)	↑	Workers found the lean layout to be safer and more ergonomic than traditional layouts.
Singh and Deokar (2018)	Multiple industries	India	Questionnaire	100 companies	Case study	5S	↑	Workplace safety was viewed as "highly improved" after 5S implementation.
Adzrie et al. (2019)	Metal fabrication—stainless steel tables	Malaysia	Survey	30 workers	Longitudinal	5S	↑	Safety initially improved after 5S introduction and continued to improve over time.
Beraldin et al. (2019)	Appliance manufacturing	Italy	Job demands research model (JDRM)	138 workers	Case study	JIT	↓	JIT has a negative effect on exhaustion, but effect can be reduced by soft lean practices (SLPs).
Bocquet et al. (2019)	Multiple industries	2 European, 1 unknown	Employee interviews	24 employees	Case studies	Multiple lean practices	↓	Lean implementation negatively affected worker stress. High involvement practices (HIP) can mitigate if fully integrated into the lean implementation.
de Negreiros et al. (2019)	Automotive component manufacturing	Brazil	Direct evaluation (QEC, WAI, NFR, JSS)	120 workers	Cross-sectional	Lean work-cell configuration	↑↓	Neutral effect on stress and other health factors.
Huo et al. (2019)	Consumer goods manufacturing	China	Survey	315 workers	Longitudinal	JIT, intensification of work	↓	Negative effects on emotional stress and physical health, mediated by supervisory support
Seddik (2019)	Garment industry	Egypt	Safety climate survey	1 company	Cross-sectional	5S	↑	5S had a positive impact on safety climate in 7 of 8 categories, neutral in 1 of 8.
Tortorella et al. (2019)	Multiple industries	Brazil	Survey	144 companies	Cross-sectional	JIT	↑↓	Neutral effect on worker health
Ulewicz and Lazar (2019)	Metal manufacturing	Poland and Romania	Surveys and public company safety data	20 companies	Cross-sectional	Unspecified lean methods or systems	↑	Companies using lean tools reported fewer critical incidents than industry average and improved further with time.
Annamalai et al. (2020)	Garment manufacturing	Tamilnadu, India	Questionnaires	80 workers	Case study	Lean production layout	↑	Positive correlation between lean production layout and safety/ergonomics
Cierniak-Emerych and Golej (2020)	Multiple industries	Lower Silesia (Poland)	Direct observations and interviews	3 companies	Case study	5S	↑↓	5S improved physical working conditions but increased stress and anxiety
Dieste et al. (2020)	Metal casting (foundry)	Italy	General observation, OCRA evaluation	600 workers	Case study	5S, TPM, and Kaizen	↑	Multiple risks and hazards were mitigated by eliminating wasteful activities.
Mousavi et al. (2020)	Multiple industries	Worldwide	Survey	112 workers and professionals	Cross-sectional	Multiple lean practices	↑↓	Lean implementation influences OHS performance, with several mediating factors
Sakthi Nagaraj and Jeyapaul (2020)	Multiple industries	India and Sri Lanka	Survey	168 workers and professionals	Cross-sectional	General lean	↑	Positive human factors outcomes are associated with successful lean implementation
Stimec (2020)	Multiple industries	France	Surveys and interviews	9 companies, 380 workers	Case studies	General lean transformation	↓	Negative perceived health effect, mitigated by team learning.

3. Article search results

The search and screening process produced 101 articles that contained a safety and ergonomic outcome resulting from LM or related methods. Most articles (n = 54) pertained to unspecified lean methods or systems. The most prevalent safety and ergonomic outcome contained in the literature was stress and mental strain (n = 36). Table 3 summarizes the LM methods and safety/ergonomic outcomes found in the articles. Some articles contain multiple lean methods or safety and ergonomic outcomes and therefore appear in the results multiple times.

3.1. Safety and ergonomic outcome categories

The safety outcomes found in the literature have been sorted into 10 categories which includes some overlapping dimensions due to the lack of detail found in many articles. For example, when a specific outcome such as physical strain was identified, it was categorized as such, even though a physical strain outcome can also be associated with a broader outcome such as general health and safety. Hazard exposure refers to the introduction of sources of harm with the potential to cause injury or death to the worker, such as mechanical energy, temperature extremes, and noise. Workload, work intensity, and exhaustive work is the one category that is not a direct safety and ergonomic outcome. However, items in this category are associated with a reduction or elimination of non-value added time, which reduces recovery time for the worker and may increase the risk for work-related musculoskeletal disorders (WMSD) (Winkel and Westgaard, 2008) and stress (van Eijnatten, 2000).

3.2. 5S outcomes

Of the outcomes pertaining to 5S, twenty-four of twenty-six contained a positive safety and ergonomic effect (Table 3). Improvements in human factors (4), hazard exposure (6), and safety performance (6) were the most common categories benefiting from 5S. Only two negative outcomes were found, where one was due to the inadvertent introduction of noise and heat hazards from the implementation (Abeysekera and Illankoon, 2016); and the other was due to worker stress resulting from fear of change (Cierniak-Emerych and Golej, 2020).

3.3. Kaizen outcomes

The literature contains safety outcomes from both kaizen related activities and their resulting changes in working conditions. Kaizen outcomes were evenly split between positive and negative at nine each, with one neutral outcome (Table 3). Negative outcomes from kaizen include higher work intensity (3) and stress (2) resulting from the changes in the workplace or work methods. Positive outcomes include human factors and ergonomic improvements (2) and hazard mitigation (2).

3.4. Just-in-time (JIT), Chaku-Chaku, and work pacing outcomes

In the literature, safety and ergonomic outcomes from JIT related methods were the most prominent among individual LM methods and had the most proportionately negative results. Twenty-three of the thirty-seven safety and ergonomic outcomes found in the literature were negative, while only three were positive and eleven had a neutral or offsetting effect (Table 3). These negative outcomes occurred in the categories of human factors and ergonomics (4), stress and mental strain (9), psychological and psychosocial well-being (1), workload and work intensity (3), safety performance/accident rates (4), and general health and well-being (2). Two of the three positive outcomes were found in one multi-case study that also listed stress as a negative outcome (Resta et al., 2016). Chaku-Chaku methods were included in these totals,

Table 3
Outcome summary with symbols for negative (●), neutral/offsetting (◐), and positive (○) safety/ergonomic outcomes.

	JIT, Work Pacing, Slack Reduction, Chaku-Chaku	Kanban	5S	Standardized Work	TPM	Kaizen, Problem Solving, Continuous Improvement	Lean Work Cell, Lean Factory Layout	TQM	HPWP	HIM	Unspecified Lean Methods or Systems
Hazard Exposure			●○○○○○○		○○	●○○	●	○			●●○
Human Factors, Ergonomics, CTD, MSD, WMSD	●●●●○		○○○○			●○○	●○○○○				●●◐○○
Overall Safety, General Health & Well-Being	●●◐◐○		○	◐			◐○○○			○	●●●◐○○○○
Physical Strain	◐					○		●			●●●
Psychological Psychosocial Well-Being	●◐										●◐
Safety and Health Perception, Safety Climate	○		○○○○○			○○		○	○○		●●○
Safety Behavior and Safety Participation											◐○
Safety Records, Accident Rate, and Safety Performance	●●●●		○○○○○○			●●○		●	○	○	●◐◐◐○○○○
Stress and Mental Strain	●●●●●●●●●◐◐◐	●	●○	◐◐◐	●○	●●○	●◐	●			●●●●●●●●◐◐
Workload, Work Intensity, and Exhaustive Work	●●●◐◐◐◐	●	○		●	●●●◐					●●●●●●●●●●●
Totals	23,11,3	2,0,0	2,0,24	0,4,0	2,0,3	9,1,9	3,2,7	3,0,2	0,0,3	0,0,2	33,9,13

contributing two negative outcomes, stress and work intensification, both from the same longitudinal study (Enríquez-Díaz et al., 2012).

3.5. Outcomes from other methods

Only one article containing two negative outcomes from Kanban was found in the literature. Eklund et al. (2007) reported negative outcomes in stress and work intensity in a multiple-method LM system that emphasized Kanban. Only five safety and ergonomic related outcomes from TPM were found in the literature, (3) positive and (2) negative (Table 3). Positive outcomes were due to hazard mitigation and stress reduction from the simplification of work (Resta et al., 2016; Dieste et al., 2020). Negative outcomes were due to work intensification and resulting increase in stress, however both outcomes were from a single study involving a multiple-method lean implementation (Eklund and Berglund, 2007). Only three studies containing five TQM outcomes were found in the literature. Leroyer et al. (2006) listed physical strain, stress and mental strain, and safety performance as negative outcomes. Resta et al. (2016) lists hazard mitigation as a positive outcome, and Yildirim (1999) found safety climate to be a positive safety and ergonomic outcome. Both positive and negative safety and ergonomic outcomes from lean factory layouts are found in the literature. Positive effects in human factors and ergonomics (4), and overall safety and health (3), were found. Negative effects on human factors/ergonomics (1), stress and mental strain (1), and increased hazard exposure (1) were also found. Neutral or offsetting effects (2) were also reported. Only three articles and four outcomes were found in the literature from standardized work, all of which were neutral to safety and ergonomics. High-performance work practices (HPWP) and high-involvement management (HIM) yielded positive outcomes in safety perception (2), safety performance (2), and overall safety and health (1) were found in three articles. No negative or neutral outcomes associated with HPWP or HIM were found in the literature (Table 3).

3.6. Unspecified lean and TPS methods or systems

The largest number of safety and ergonomic outcomes found in the literature were resulting from unspecified lean methods or systems. The literature contains fifty-five outcomes, most of which are negative (Table 3). These negative outcomes are in the categories of human factors and ergonomics (2), physical strain (3), stress and mental strain (8), psychological and psychosocial well-being (1), workload and work intensity (11), hazard exposure (2), safety perception and climate (2), overall safety and health (3), and safety performance (1). Positive outcomes were in the categories of human factors and ergonomics (2), hazard exposure (1), safety perception and safety climate (1), safety behavior and participation (1), overall safety and health (4), and safety performance (4). Several neutral or offsetting outcomes (9) were also found in the literature.

Outcomes from unspecified lean methods or systems in the categories of physical strain and stress/mental strain were numerous and mostly negative (11) or neutral (2), with no positive outcomes. Conversely, safety performance, which includes accident and severity rates, was mostly positive (4) or neutral (3) and rarely reported as negative (1).

4. Discussion

In his book “Toyota Production System: An Integrated Approach to Just-in-Time”, Monden (2011) states that one goal of the TPS is “respect for humanity, or morale, which must be cultivated while the system utilizes human resources to attain its cost objectives.” Womack et al. (1990) describes LM as “humanly fulfilling.” And Liker (2004), quoting Ohno, stated that “safety is the foundation of all our activities” in reference to the TPS.

However, some literary claims exist that challenge the assertion that LM is a safe and worker-empowering system. Babson (1993) reported that Ohno’s original purpose for Kaizen was for workers to figure out how to return to normal production levels after he removed 10 percent of the workforce; a process that was repeated each time equilibrium was reached. And, according to Alcaraz (2014), JIT waste reduction efforts have evolved to include increasing worker capacity, while Weingarten (2017) associated a 1% decrease in worker slack (increase in worker capacity) with a 0.69% increase in workplace injuries.

Therefore, the objective of this review was to determine whether specific LM methods uniquely contributed to safety and ergonomic outcomes, thus adding detail to this complex topic. As hypothesized, some LM methods uniquely contributed to safety and ergonomic outcomes, as the two most prominently mentioned methods in the literature contained biased and opposing outcomes. Some explanation as to why contradicting viewpoints exist concerning the relationship between LM and safety/ergonomics might be found by determining whether a LM implementation has a disproportionate focus on one of these impactful methods.

It is not surprising that some methods resulted in positive safety and ergonomic outcomes. 5S lends itself well to safety improvement, so much so that safety is often considered as a direct benefit of 5S implementation (Veres et al., 2018; Mutaza et al., 2020). Likewise, a typical goal of a kaizen event is the enhancement of safety in a particular area (Vieira et al., 2012), often implementing 5S methods in this effort (Zocca et al., 2018). Also, the employee-involvement aspect of kaizen tends to have a positive impact on worker stress by giving workers more job control (Conti et al., 2006). A lean factory layout is composed of a group of dissimilar processes operated by multifunctional workers, thus repetitive motion is reduced, along with ergonomic risk (Hunter, 2001). HPWP and HIM are both worker-focused methods of increasing performance through employee involvement and engagement (Böckerman et al., 2012; Tregaskis et al., 2013), so positive outcomes from these methods could also be expected.

Few safety and ergonomic outcomes were found that resulted from TPM and TQM, and those results were evenly positive and negative. TPM and TQM are not methods that directly affect the workplace like 5S, or that change worker motion characteristics like the lean factory layout, thus a small number of outcomes and mixed results associated with these methods is unsurprising. Likewise, standardized work is concerned with publishing a standardized sequence of operations (Hussain et al., 2016) rather than changing how the work is performed, so a small number of outcomes, all with neutral safety and ergonomic effects, was a plausible finding in the literature.

Only two outcomes were associated with Kanban, negative effects on stress and work intensity, both from the same study that examined a newly introduced LM system. It is possible that the change itself was the source of the stress outcome, as newly employed persons without experiences of the previous system accepted the new system better (Eklund and Berglund, 2007). Kanban is a material flow system, so the work intensity outcome might be attributed to the removal of slack from the overall LM system, rather than the Kanban method itself.

The large number of negative results from JIT and related methods are understandable given that JIT attempts to remove slack and therefore increases work intensity. In a Chaku-Chaku system, the cycle time of the machine(s), and the possibility that the load-unload rate may be machine controlled, can create ergonomic problems through work intensity and a set frequency of motion for the worker. Other methods to enhance JIT through work pacing, such as piece-rate policies that base worker wages on quantity of pieces produced, may have a likewise effect on work intensity.

4.1. Review summary

Just as with the contradicting claims about the design intent of LM concerning worker well-being, the LM related safety and ergonomic outcomes found in the literature are also contradictory. Our research found 101 articles containing safety and ergonomic outcomes from LM, in which 37 had positive outcomes, 39 had negative outcomes, and 25 contained neutral or offsetting outcomes. However, some clarity can be found by examining details of the LM methods used, the specific safety and ergonomic outcomes resulting from these methods, along with other details from these studies.

This review found that use of JIT resulted in negative safety/ergonomic outcomes in 62% of occurrences found in the literature, most commonly in the category of stress and mental strain. On the other hand, the use of 5S resulted in a positive outcome in 92% of cases, impacting several safety and ergonomic dimensions. Such a wide disparity of outcomes in the two most common methods found in the literature is a matter to consider when examining the unclear relationship between LM and safety/ergonomics.

4.2. Areas for future research

Krafcik (1988) noted that cultural differences between native Japanese TPS and transplanted TPS affected efficiency outcomes. Likewise, there is an indication that the country and/or culture where LM practice occurs influences the relationship between LM and safety and ergonomics. Brown and O'Rourke (2007) established that obstacles to effective worker participation in China must be overcome to realize safety under LM, whereas Kumar and Kumar (2016) found that Indian culture embraces the idea that worker participation is a necessary component of LM. Our research harmonizes with this view, as all outcomes in this review that took place in China, along with France, had exclusively negative outcomes; while outcomes that occurred in India were entirely positive. Scientific confirmation of this notion, along with how these cultural differences manifest into variations in safety and ergonomic outcomes, would be a meaningful contribution to the LM and Safety/Ergonomic communities.

There are signs that unionized companies experience disproportionately negative safety and ergonomic outcomes (Kaminski, 2001). This outcome might be attributed to automobile manufacturing companies, as they have a high propensity for both unionization and LM adoption. Regardless, a determination of what effect unionization has on the relationship between LM and safety and ergonomics would also be a meaningful contribution to the literature.

Ergonomic assessment methods such as OCRA (Occupational Repetitive Actions), RULA (Rapid Upper Limb Assessment), and REBA (Rapid Entire Body Assessment) are designed to determine safety and ergonomic risk in work activities. An increase in work intensity is a common outcome from LM systems and methods, especially JIT. Therefore, a derivative method of determining a work frequency limit, based on the movement details of a particular job, would benefit managers and engineers in the design and implementation of a JIT system.

The review findings also indicate that different industries experience different results from LM implementation and methods. For example, our research concurs with Koukoulaki (2014), in that negative safety and ergonomic outcomes in the automotive industry are more evident than other industries. Conversely, the textile industry had only positive outcomes from our research. Experimental confirmation of this tendency, and determination of causes for differences, would also be a meaningful contribution.

The number of respondents in the study sample group also appeared to have some bearing on the nature of the outcome. A sample size of 150 people or less resulted in about 2 to 1 positive to negative outcomes. On the other hand, a sample size of more than 150 people contained more negative outcomes than positive by about a 5 to 1 ratio. One category that stands out is the effect of unspecified lean methods or systems on workload and work intensity, where all eleven negative outcomes were found with sample sizes larger than 150. These tendencies may imply that company size is associated with safety and ergonomic outcomes due to LM, or that negative outcome data might be suppressed by smaller sample sizes.

A national or regional cross-sectional study could be used to demonstrate associations between several of these factors within relationship between LM and safety and ergonomics. Effects from factors such as culture, industry type, LM methods used, LM maturity, employee demographics, union status, and company size could be determined from such a large sample size. An employee-perceived safety climate survey, which has been demonstrated to have association with safety behavior and injury data (Zohar, 2000; Zohar and Luria, 2005), could be used to determine safety outcome (dependent variable) if actual injury data cannot be obtained. If the other factors (independent variables) can also be defined with survey questions, such a large cross-sectional study might be feasible.

The aptitude of the LM systems and methods is generally unstated in the literature. However, if the safety and ergonomic outcomes occurred in an incomplete or poorly designed LM method or system, then these outcomes might be attributed to a poorly functioning system. The use of a survey to assess the state of a lean implementation, such as the survey by Huang, Harris, and Loyd (Huang et al., 2021), could be compared to safety data to determine if lean aptitude has any bearing on safety and ergonomic outcomes. Company incident rates are publicly available from the Occupational Safety and Health Administration (OSHA) and NIOSH, which could be used to define the safety and ergonomic component of the study.

While most of the literature search results pertained to front-line manufacturing workers, two studies contained outcomes for managers. Hussain, Rehman, Case, Masood, and Habib (Hussain et al., 2016) found that standardized work created less stress for white-collar workers in a case study in Pakistan. Conversely, Huo and Boxall (2017) found role overload to be a risk in a case study of 226 front-line LM managers in China. The effect of LM on supervisors and managers is another opportunity for meaningful research.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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