# The Effects of Lean Manufacturing on Occupational Safety and Ergonomics

by

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Abstract

The association between Lean Manufacturing (LM) and occupational safety and ergonomics (S/E) is a widely disputed topic in scientific literature. This study attempts to add clarity to this controversial relationship through literature review and experimental analysis. From the literature review, one hundred and one studies containing one hundred and seventy LM-related safety/ergonomic outcomes were identified. Thirty-seven outcomes pertained to the use of Just-in-Time (JIT) production, which were overwhelmingly negative in nature. Conversely, the twenty-six studies pertaining to 5S contained almost exclusively positive outcomes. No outcomes from the adoption or use of Lean Culture were found. These review findings suggest that individual LM methods, especially JIT and 5S, uniquely contribute to the safety/ergonomic outcomes attributed to LM, while the effects from Lean Culture, the principle that emphasizes respect for the worker, remain unknown.

Based on the review findings, a method was designed to test the effect of LM principle adoption levels on S/E. Surveyed employee perception of LM adoption levels in the principles of Standardization and Stability, Built-in-Quality, JIT, and Lean Culture were used to define the independent variables; based on a 7-point Likert scale. The dependent variables were made up of safety incident rates from the Occupational Safety and Health Administration (OSHA), normalized to industry standard rates from the Bureau of Labor Statistics (BLS), for each studied manufacturing facility. These dependent variables took the form of normalized total case rate (TCR); rate of cases requiring days away, restricted, or transferred (DART); and rate of cases requiring days away from work due to injury or illness (DAFWII). Regression analysis and structural equation modeling (SEM) methods were the selected methods to study the relationships.

Survey invitations were sent to 361 American manufacturing facilities, and after removal of invalid responses and extreme outliers from the received responses, 271 valid responses from 15 facilities remained. Dependent variables from the associated facility were added to each survey response to complete the data set. An exploratory analysis of this data resulted in some hints of association between both Culture and JIT adoption levels on incidence rates, but none pertaining to Standardization and Stability. Results from multiple regression analysis confirmed these indications, finding significant effect coefficients pertaining to both JIT and Culture adoption levels, yet still no significant results pertaining to Standardization and Stability, the principle containing 5S. These regression results were successfully corroborated through SEM, robust regression, and non-parametric tests; due to the non-normal distributions and Likert data contained in the data set.

The analysis found that higher employee-perceived Lean Culture adoption was associated with lower TCR and DART rates, while higher perceived JIT adoption was associated with higher incidence rates. The effect coefficients indicate that a 1-point Likert-scale increase in perceived JIT adoption level was associated with 0.445 more total cases and 0.346 more DART cases per 100 workers per year, while Culture adoption indicated 0.518 fewer total cases and 0.373 fewer DART cases. Adjusted $R^2$ values from this analysis indicated that this JIT/Culture multi-regression model explained 5% of the variance in total case incident rate and 6% of the variance in DART rate.

The results from this study suggest that LM implementation does indeed have a small influence on S/E, and that influence is beneficial so long as Culture adoption occurs at an equal or higher rate than that of JIT. However, JIT adoption with lagging or absent Culture adoption can result in a negative S/E effect in an LM implementation.

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## List of Abbreviations

| | |
|---|---|
| 5S | Seiri (sort out), Seiton (set in order), Seiso (shine/sweep), Seiketsu (standardize), and Shitsuke (sustain) |
| ACGIH | American Conference for Governmental Industrial Hygienists |
| Cal-OSHA | California Occupational Safety and Health Administration |
| CI | Continuous Improvement |
| CAMI | Canadian Automotive Manufacturing Inc. |
| CMDQ | Cornell Musculoskeletal Discomfort Questionnaire |
| CTD | Cumulative Trauma Disorder |
| DAFWII | Days Away from Work due to Injury or Illness |
| DAFWIIsc | Days Away from Work due to Injury or Illness—Score |
| DART | Days Away, Restricted, or Transferred |
| DARTsc | Days Away, Restricted, or Transferred—Score |
| DV | Dependent Variable |
| HAL | Hand Activity Limit |
| HIM | High-Involvement Management |
| H&S | Health and Safety |
| HPWP | High-Performance Work Practices |
| JIPM | Japan Institute of Plant Maintenance |
| IDEEA | Intelligent Device for Energy Expenditure and Physical Activity |
| IRB | Institutional Review Board |
| IV | Independent Variable |
| JDRM | Job Demands Research Model |

| | |
|---|---|
| JIT | Just-in-Time |
| JSS | Job Stress Scale |
| LM | Lean Manufacturing |
| MIT | Massachusetts Institute of Technology |
| MSD | Musculoskeletal Disorder |
| NAICS | North American Industry Classification System |
| NASA-TLX | National Aeronautics and Space Administration—Task Load Index |
| NFR | Need for Recovery Scale |
| NIOSH | National Institute for Occupational Safety and Health |
| NUMMI | New United Motors Manufacturing Inc. |
| OCRA | Occupational Repetitive Actions |
| OHS | Occupational Safety and Health |
| OPEC | Organization of Petroleum Exporting Countries |
| OSHA | Occupational Safety and Health Administration |
| PEP | Program Evaluation Profile |
| QEC | Quick Exposure Check |
| REBA | Rapid Entire Body Assessment |
| RULA | Rapid Upper Limb Assessment |
| S/E | Safety and Ergonomics |
| SI | Strain Index |
| SLP | Soft Lean Practices |
| SEM | Structural Equation Modeling |
| SMED | Single Minute Exchange of Dies |
| S&S | Standardization and Stability |

| | |
|---|---|
| TCR | Total Case Rate or Total Case Incident Rate |
| TCRsc | Total Case Rate—Score |
| TLV | Threshold Limit Value |
| TPS | Toyota Production System |
| TPM | Total Productive Maintenance |
| TQM | Total Quality Management |
| US | United States |
| USA | United States of America |
| WAI | Work Ability Index |
| WIP | Work-in-Process |
| WMSD | Work-Related Musculoskeletal Disorder |
| WWII | World War II |

# Chapter 1 Introduction

## 1.1 Background

Toyota, the Japanese car company that revolutionized manufacturing and grew to be the world's largest motor vehicle producer in 2009 [1], began humbly in the 1800s as a small family-owned textile business [2, 3]. According to Womack, Jones, and Roos [4], the Toyota Motor Company was founded in 1937 when this family-owned textile equipment company was converted to manufacture military trucks in the lead up to World War II (WWII).  Womack et al. [4] continues that the Toyoda family (the car company was renamed "Toyota" for marketing purposes) had long aspired to build cars, and this wartime opportunity laid the groundwork for pursuit of this goal.  However, in post-WWII Japan, the economic conditions were hardly favorable for an upstart car company.

Even before the war, Japan had failed to achieve the same level of manufacturing success as America.  According to Ohno [2], Japanese pre-war productivity in car manufacturing was estimated to be inferior to American productivity by a ratio of 10 to 1, as Japan was still using artisan methods while American automakers were using a refined mass-production system.  To be successful, Toyota would not only have to overcome this productivity gap, but also overcome post-war obstacles such a small domestic market, American intervention in labor disputes, unavailability of capital, and foreign car manufacturers eager to establish operations in Japan [4]. Toyota barely survived the years following WWII, reaching a low point in 1950 where 25% of employees were laid off and the company president, Kiichiro Toyoda, resigned amidst a labor dispute [2].  By 1950 Japan had a negative net worth [5], and Toyota had still produced fewer cars in the five years after the war than one Ford plant was producing in a single day [4].

That same year, however, saw the beginning of the Korean War; and the subsequent economic expansion helped facilitate an economic recovery for Japan [2]. In 1951, the growth rate in Japan reached 12%, buoyed by economic cooperation between Japan and the United States (US) in support of the Korean War effort [6]. Toyota was a co-benefactor in these improving conditions and by 1955 had launched its first domestically produced genuine passenger car, the Crown, in a historic event for the Japanese automobile industry comparable to the appearance of America's Ford Model T in 1908 [7, 8]. That year was also historic for the US, as it reached a record 7 million cars sold domestically; but 1955 ironically marked the beginning of a downhill slide in market share owned by American automakers, largely due to broad international adoption of Ford's mass-production techniques [4].

Toyota relied on several production innovations to reach the celebrated launch of its first passenger car. 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 [9]. 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 [9]. Jidoka, the empowerment of workers to exercise their own judgement and halt production when quality or other problems were encountered, was yet another anti-Fordist concept that developed prior to 1955 [9, 10].

However, the most significant Toyota innovations of this post-WWII period were the concepts of just-in-time (JIT) production and Kanban "pull" supply systems. These systems featured the arrival of components at the right time and in the right quantity [10], preventing both stock-outs and overstocking/overproduction. This was accomplished by ordering components when needed, or "pulling" [11], rather than ordering/producing and stocking components in advance based on an estimated forecast of need, or "pushing" [12]. The aim of JIT is to produce and deliver finished goods just in time to be sold, subassemblies just in time to be assembled into finished goods, fabricated parts just in time to go into subassemblies, and purchased materials just in time to be transformed into fabricated parts [13].

Kanban is an operational control system for JIT [14], and is defined as a material flow-control mechanism for controlling the proper quantity and time to realize only the quantity of products that are strictly necessary [15]. In a Kanban system, the demand of the current stage depends on the demand of the subsequent stages, i.e. the preceding stage must produce only the exact quantity withdrawn by the subsequent manufacturing stage [16]. Kanban is the Japanese word for visual record or card, and such cards are used to signal production authorization or component delivery of a given amount of material [17]. These cards, or "Kanbans", are sent to the supply source and then returned with the materials ordered; continuing in this circulation to control production and material flow [16]. Kanban would be adopted by Toyota company-wide in 1962 [2].

Toyota grew from 23,000 vehicles produced in 1955 to 1.6 million in 1970 [10], volumes that increasingly made a Fordist mass-production system attractive. Yet Toyota resisted the temptation to use American mass-production techniques, thinking it dangerous to blindly imitate the Ford system [18]. Rather, Toyota continued creating a flexible system whose efficiency was not dependent on long production runs [10]. Besides, larger volume sales would be offset by increasing product proliferation after the 1960s [19], suppressing production lot sizes. While Toyota would eventually attempt to adopt certain elements of American Fordism, particularly in transplant factories in other countries; it still practiced small-lot production, maintained low inventory levels, and kept other hallmark Toyota manufacturing traits intact [19].

In response to the continued need for smaller lot sizes, Toyota sought to minimize unproductive machine setup time, in a concept known as single-minute exchange of dies (SMED) [20]. Setup time can be divided into two groups of activities; internal, which can only be performed when the machine is stopped; and external, which can be performed when the machine is still in operation [11]. The focus of SMED is to transform internal activities into external ones, and to minimize the time required for the remaining internal activities [20]. Using the SMED technique, Toyota was able to reduce the setup time in a pressing department from two or three hours from 1945-1954, to a quarter hour from 1955-1964, and by 1970 the setup time had improved to only three minutes [18]. Toyota had found a way to run small lots consecutively with almost no interruption, minimizing the economy-of-scale advantage of mass-production.

While not formalized until later, several other methods originated in the post-WWII era. Total productive maintenance (TPM) is an employee-involved method of improving machine performance [21], to maximize its utilization and forego further investment in machinery [22]. The Japan Institute of Plant Maintenance (JIPM) was the first to define TPM in 1971 [21]. 5S, a method to create a cleaner and more efficient workspace [23], was not a formalized term until 1980 [24].

During the 15-year period beginning in 1959-1960, Japan experienced unusually rapid economic growth [2], and by 1970 Toyota was producing over a million cars a year [10]. But 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 [25]. 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 [2].

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 (along with many Japanese manufacturers in other industries) had adopted JIT [26]. By 1980, Toyota and other Japanese auto manufacturers had become so competitive using the TPS system that they had gained a 22.2% market share in US passenger car sales [27]. 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 [28]. In response to the loss of market share, American industry became focused on how Japanese manufacturing methods could be adopted in the US.

Prior to adoption by American car companies, however, the TPS concept began practice in North America in the early 1980s through Japanese "transplant" companies operating in the US and Canada [29]. For example, Honda began production in their Marysville, Ohio factory in 1982; Nissan in Smyrna, Tennessee in 1983; and Toyota (with General Motors) in Fremont, California in 1984 [30]. These transplant companies, like native Japanese companies, consistently outperformed American car companies in both productivity and quality [4, 31]. Evaluating the reasons for the disparity, John Krafcik [31] 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" [4] and "Lean Thinking" [32], which led to the mainstream establishment of "lean" as a manufacturing model [33, 34]. In the book "Lean Thinking", Womack and Jones [32] state that "…lean thinking is lean because it provides a way to do more with less and less – less human effort, less equipment, less time, and less space – while coming closer and closer to providing customers with exactly what they want."

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 [2, 11, 18, 33, 35, 36]. Despite being essentially a re-branding of TPS, LM is the system that would gain worldwide adoption [37]. The interchangeability of the terms LM and TPS is debatable, as some authors claim that LM does not share the "respect for humanity" found in the TPS [2, 33, 38, 39]. Others assert that the TPS, from its inception, was a system designed to exploit workers [40, 41]. Setting aside controversial differences, this research uses the LM and TPS terms interchangeably from here forward.

Although LM is designed to be a worker-empowering system [42], waste reduction efforts sometimes lead to shortened cycle times, which have the drawback of intensifying employee workload [43]. Evidence to the claims that LM was harmful to workers began to emerge. A high incidence of carpal tunnel syndrome was reported at the Tennessee Nissan plant in 1988 [44]. Increasing prevalence of worker's compensation claims at the Michigan Mazda plant was reported in 1990 [45]. And increased worker stress at Canadian Automotive Manufacturing Inc. (CAMI), a Suzuki-General Motors factory in Ontario, was discovered in 1991 [46]. However, the landmark case would occur at the New United Motors Manufacturing, Inc. (NUMMI), a joint venture between General Motors and Toyota located in California. According to Adler, Goldoftas, and Levine [47], NUMMI was lauded for achieving performance based on the high employee involvement afforded by the TPS, yet the company was cited in 1993 by California's Occupational Safety and Health Administration (Cal-OSHA) for high ergonomic injury rates [47]. While the TPS production system was implied as the cause of these ergonomic hazards, the same authors published a study the following year attributing a poorly planned new model launch to the ergonomic hazards rather than the new manufacturing system [48]. Yet the perception that LM increases efficiency at the expense of employee well-being would persist, as literature critical to LM continued to emerge [49-51].

Amid increasing concerns about safety and ergonomics (S/E), 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 [52]. 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 S/E [51, 53, 54], and the topic continues to be studied and debated to this day [55].

## 1.2 Specific Aims

The aim of this research is to investigate the relationship of LM with occupational S/E. Specifically, the aim is to determine how individual lean methods affect S/E outcomes. An extensive literature review was conducted to discover these effects and provide direction for the experimental design. From these findings, a cross-sectional study of manufacturing companies was designed and conducted to determine associations between LM methods and safety/ergonomic outcomes, using company specific data.

# Chapter 2 Review of the Literature

## 2.1 Introduction

To adequately investigate the effect of LM on occupational S/E, a review was conducted with the goal of examining the literature describing the relationship. The literature search sought articles published between 1980 and 2020, prior to worldwide adoption and 8 years before the term “lean” was introduced by Krafcik, attempting to gather all available literature on the topic. The purpose of this review was to document the body of literature at a higher level of detail and discover which LM methods (inputs) lead to which S/E outcomes (outputs).

## 2.2 Article Search Method

A systematic search and review were conducted based on methods proposed by Grant and Booth [56] 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. These databases are available to Auburn University faculty and students and were chosen for their possession of both general science and safety/ergonomic content. 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 counterintuitively yielded fewer and more relevant 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

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” |

chapters were excluded as part of the search setting. The focus of our research is on the worker in the 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 S/E 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 (Table 2). 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 relevance, 70,474 records were excluded. A full article screening (n=2,341) eliminated 1,760 articles that lacked a safety or ergonomic outcome, and 131 duplicates were removed. The remaining articles (n=349) were 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 11.

Table 2: Totals from Article Search and Screening Process

| | **Google Scholar** | **Science Direct** | **Web of Science** | **Ergo-nomics Abstracts** | **PubMed** | **Found in Articles** | **Total** |
|---|---|---|---|---|---|---|---|
| Search Fields | 1,2 | 1,2 | 1,2,3 | 1,2,3 | 1,2,3 | N/A | N/A |
| **Total Search Results** | **69,567** | **2,835** | **174** | **95** | **52** | **N/A** | **72,815** |
| Abstracts Screened Non-Mfg. | 67,807 | 2,496 | 93 | 47 | 31 | N/A | -70,474 |
| **Articles Accepted** | **1,760** | **339** | **81** | **48** | **21** | **92** | **2,341** |
| Duplicates Removed | 0 | 30 | 35 | 18 | 13 | 35 | -131 |
| Articles Screened Non-Safety | 1,431 | 243 | 25 | 13 | 7 | 41 | -1,760 |
| **Articles Accepted** | **329** | **66** | **21** | **17** | **1** | **16** | **450** |
| Full Article Review | 236 | 64 | 21 | 17 | 1 | 10 | -349 |
| **Articles Accepted** | **93** | **2** | **0** | **0** | **0** | **6** | **101** |

## 2.3 Article Search Results

The search and screening process produced 101 articles that contained a S/E outcome resulting from LM. The identified articles listed several S/E outcomes and cited the use of a variety of LM methods such as 5S, JIT, and Kanban as causal factors for those outcomes. The use of several LM-related methods such as Total Quality Management (TQM), High Performance

Work Practices (HPWP), and High Involvement Management (HIM) were also found to have associated S/E outcomes in these articles. Most articles (n=55) pertained to unspecified lean methods or systems, where multiple methods are used concurrently or where a specific method is not specified.

### 2.3.1 Safety and Ergonomic Outcome Categories

The safety outcomes found in the literature have been classified into 10 different categories (Table 3). These categories are comprised of 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 S/E outcome. However, items in this category are associated with a reduction or elimination of non-value added time, which could

Table 3: Categories of Safety and Ergonomic Outcomes

1. Hazards
2. Human Factors, Ergonomics, Cumulative Trauma Disorder (CTD), Musculoskeletal Disorder (MSD) or Work-Related Musculoskeletal Disorder (WMSD).
3. Overall Safety, General Health and Well-Being
4. Physical Strain
5. Psychological/Psychosocial Well-Being
6. Safety and Health Perception, Safety Climate
7. Safety Behavior and Safety Participation
8. Safety Records, Accident Rate, and Safety Performance
9. Stress and Mental Strain
10. Workload, Work Intensity, and Exhaustive Work

reduce recovery time for the worker and may increase the risk for work-related musculoskeletal disorders (WMSD) [57] and stress [58]. Appendix A contains a summary of references containing safety/ergonomic outcomes associated with individual LM methods.

### 2.3.2 5S

5S is an acronym representing the Japanese terms *seiri* (sort out), *seiton* (set in order), *seiso* (shine/sweep), *seiketsu* (standardize), and *shitsuke* (sustain) [59]. The purpose of a 5S implementation is to create a cleaner and more efficient workspace to minimize unnecessary movement and time spent searching for tools or other needed items [23]. This method directly addresses two of the seven wastes identified in LM principles: unnecessary motion and waiting.

Of the outcomes pertaining to 5S, 24 of the 26 contained a positive S/E outcome. Improvements in human factors (4), hazard exposure (6), and safety performance (6) were the most common categories benefiting from 5S. Of the (2) negative outcomes, one was due to the inadvertent introduction of noise and heat hazards from the implementation [60]; and the other was due to worker stress resulting from fear of change [61]. A summary of the literature containing S/E outcomes from 5S can be found in Table 4.

### 2.3.3 Kaizen

Kaizen is a Japanese term that means continuous improvement, taken from the words ‘kai’, which means continuous, and ‘zen’, which means improvement [62]. While the original practice of kaizen consisted of small, incremental improvements over an extended time period [63], kaizen “events” are Western adaptations of these TPS activities that originated in Japan [64]. The purpose of a kaizen event is to improve business performance through employee-involved short-term projects. These events are targeted to a specific work area, use cross-functional teams from all management levels, and are designed to achieve specific goals in a short amount of time

Table 4: Articles Containing Safety and Ergonomic Outcomes from 5S and Kaizen

| Safety/Ergonomic Category | 5S | Kaizen, Problem-Solving, & Continuous Improvement |
|---|---|---|
| Human Factors, Ergonomics, CTD, & WMSD | (+) [24, 60, 66, 67] | (-) [47]<br>(+) [60, 67] |
| Physical Strain | | (+) [68] |
| Stress & Mental Strain | (-) [61]<br>(+) [69] | (-) [70, 71]<br>(+) [72] |
| Workload, Work Intensity, Exhaustive Work | (+) [69] | (-) [70, 73, 74]<br>(+/-) [75] |
| Hazards | (-) [60]<br>(+) [24, 61, 66, 67, 76, 77] | (-) [60]<br>(+) [67, 77] |
| Safety & Health Perception, Safety Climate | (+) [78-82] | (+) [68, 71] |
| Overall Safety, General Health & Well Being | (+) [83] | |
| Safety Records, Accident Rate, Safety Performance | (+) [66, 84-88] | (-) [45, 47]<br>(+) [88] |

[65]. Any of the seven LM wastes may be the focus of kaizen improvement efforts, whether through the traditional, ongoing kaizen or through kaizen events.

The literature contains safety outcomes from both kaizen related activities and the resulting changes in working conditions. Kaizen outcomes were evenly split between positive and negative at eight each, with one neutral outcome. 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). A summary of the literature containing S/E outcomes from kaizen can be found in Table 4.

### 2.3.4 Just-in-Time (JIT), Chaku-Chaku, and Work Pacing

JIT production is the hallmark feature of LM. The purpose of a JIT system is to manufacture products in the quantity needed, at the time needed. These features focus on the wastes of overproduction and excess inventory. JIT not only pertains to the final-product phase of the manufacturing process, but to raw material inventory and all value-adding activities in between. According to Wiengarten, Fan, Lo, and Pagell [89], slack is defined as "the pool of resources in an organization that is in excess of the minimum necessary to produce a given level of organizational output". In a JIT system, both slack and work-in-process (WIP) inventory are reduced [89, 90].

A Chaku-Chaku (Japanese: load-load) system is a form of JIT realization [91]. Such a system contains a machine or series of machines that add value to the product, while a worker loads and unloads the machine(s). Work pacing, and piece rate policies that base worker wages on quantity of pieces produced, were considered as JIT related methods due to their promotion of work intensity. While these policies are limited by labor law restrictions in the US [92], their use may be commonplace in emerging economies [93].

In the literature, S/E outcomes from JIT related methods were the most prominent among individual LM methods and had the most negative results. Twenty-one of the thirty-five S/E outcomes found in the literature were negative, while only two were positive and eight had a neutral or offsetting effect. These negative outcomes occurred in the categories of human factors and ergonomics (4), stress and mental strain (8), psychological and psychosocial well-being (2), workload and work intensity (2), safety performance/accident rates (4), and general health and well-being (2). The only two positive outcomes, ergonomics and safety performance/accident rate, were found in one multi-case study that also listed stress as a negative outcome [94].

Chaku-Chaku methods resulted in two negative outcomes, stress and work intensification, both from the same longitudinal study [91]. Articles containing S/E outcomes from JIT-related methods are listed in Table 5.

Table 5: Articles Containing Safety and Ergonomic Outcomes from JIT and Kanban

| Safety/Ergonomic Category | JIT, Work Pacing, Slack Reduction, Chaku-Chaku | Kanban |
|---|---|---|
| Human Factors, Ergonomics, CTD, & WMSD | (-) [47, 72, 95, 96]<br>(+) [94] | |
| Physical Strain | (+/-) [97] | |
| Stress & Mental Strain | (-) [72, 91, 94, 98-103]<br>(+/-) [97, 104, 105] | (-) [70] |
| Psychological/Psychosocial Well-Being | (-) [101]<br>(+/-) [106] | |
| Workload, Work Intensity, Exhaustive Work | (-) [91, 100, 107]<br>(+/-) [13, 75, 108, 109] | (-) [70] |
| Safety & Health Perception, Safety Climate | (+) [109] | |
| Overall Safety, General Health & Well Being | (-) [98, 103]<br>(+/-) [104, 110]<br>(+) [94] | |
| Safety Records, Accident Rate, Safety Performance | (-) [45, 47, 89, 111] | |

### 2.3.5 Kanban

Kanban is a material flow method that minimizes inventory, including WIP inventory, in support of a JIT system [15]. Kanban is a simple pull system that uses cards to signal replenishment of bins or other containment. The number of cards/bins is dependent on several factors including replenishment lead-time, economic order quantity, and the estimated usage rate of the material or part and can be calculated. When properly implemented and practiced, such a system prevents excessive inventory [112] and overproduction, yet guarantees part availability. Kanban is designed to address the wastes of excess inventory, overproduction, and waiting. Only one article containing two negative outcomes was found in the literature. Eklund et al. [70] reported negative outcomes in stress and work intensity (Table 5) in a multiple-method system that emphasized Kanban.

### 2.3.6 Total Productive Maintenance (TPM)

TPM is an employee-involved method of improving and maintaining the performance of machinery and machine-dependent processes [21]. A main purpose of TPM is to increase machine availability to minimize additional capital investment in equipment [22]. TPM is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns, and promotes autonomous maintenance by operators through day-to-day activities involving the total workforce [113, 114]. TPM is intended to reduce non-productive time and the production of defective products, both of which are considered as losses in machine availability, addressing the LM-defined wastes of waiting and defects.

Only five S/E related outcomes were found in the literature, (3) positive and (2) negative. Positive outcomes were due to hazard mitigation and stress reduction from the simplification of work [77, 94]. Negative outcomes were due to work intensification and resulting increase in stress, however both outcomes were from a single study involving a multiple-method LM implementation [70]. A summary of literature containing S/E outcomes associated with TPM can be found in Table 6.

### 2.3.7 Total Quality Management (TQM)

TQM is a philosophy of management that focuses on achieving customer satisfaction by continuously improving product quality and value, and engaging all employee levels in the

Table 6: Articles Containing Safety and Ergonomic Outcomes from TPM and TQM

| Safety/Ergonomic Category | TPM | TQM |
|---|---|---|
| Physical Strain | | (-) [120] |
| Stress & Mental Strain | (-) [70]<br>(+) [94] | (-) [120] |
| Workload, Work Intensity, Exhaustive Work | (-) [70] | |
| Hazards | (+) [77, 94] | (+) [94] |
| Safety & Health Perception, Safety Climate | | (+) [121] |
| Safety Records, Accident Rate, Safety Performance | | (-) [120]<br>(+) [121] |

organization toward that effort [115, 116]. While TQM is not part of TPS lexicon, it is similar to the TPS in its post-WWII Japanese origins, the 1980s adoption by the U.S., its element of employee involvement, and the collaboration between Juran, Deming, and Ishikawa, founders of TQM, with Ohno and Shingo, founders and pioneers in TPS [115, 117, 118]. TQM is designed to contend with waste primarily in the form of defects, although any waste that affects customer satisfaction may also be addressed. To reward exemplary TQM initiatives, the U.S. Department of Commerce instituted the Malcolm Baldrige Quality award in 1987 [119], a recognition process that remains in place today.

Only three studies containing six TQM outcomes were found in the literature. Leroyer et al. [120] listed injury rate, strain, and stress as negative outcomes. Resta et al. [94] lists reduced risks as a positive outcome, and Yildirim [121] found safety perception and accident rates to be positive S/E outcomes. Table 6 contains a summary of literature containing S/E outcomes from TQM.

### 2.3.8 Lean Work Cell and Lean Factory Layout

Another key feature of a LM system is an interlinked factory floor arrangement conducive to flexible staffing and more receptive to product design changes and technological advancement in process technologies [122]. The "U-shaped" work cell is a typical component of such a system, which is designed to minimize walking distance for multi-tasking workers, increase floor space utilization, and improve communication between workers [123]. Hunter [124] found many ergonomic advantages to the lean work cell arrangement, including the reduction of repetitive motion risks, but also contained disadvantages such as increased work intensification from job enlargement. These factory arrangements act to reduce the wastes of transportation, motion, and WIP inventory.

Both positive and negative S/E 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. A summary of articles containing these outcomes can be found in Table 7.

Table 7: Articles Containing Safety and Ergonomic Outcomes from Lean Layout and Standardized Work

| Safety/Ergonomic Category | Lean Work Cell & Lean Factory Layout | Standardized Work |
|---|---|---|
| Human Factors, Ergonomics, CTD, & WMSD | (-) [125]<br>(+) [123, 126-128] | |
| Stress & Mental Strain | (-) [129]<br>(+/-) [130] | (+/-) [68, 104, 131] |
| Hazards | (-) [129] | |
| Overall Safety, General Health & Well Being | (+/-) [130]<br>(+) [126-128] | (+/-) [104] |

### 2.3.9 Standardized Work

Standardized work, as the name implies, is a documented procedure for a work task that is transferrable to any worker performing that task [132]. The purpose of standardized work is to eliminate the variability in processes while increasing the feasibility of interchangeable workers. Standardized work is aimed at eliminating the waste of defects. Three articles and four outcomes were found in the literature, all of which were neutral to S/E. A list of these articles can be found in Table 7.

### 2.3.10 High-Performance Work Practices and High-Involvement Management

High-Performance Work Practices (HPWP) and High-Involvement Management (HIM) are LM-based systems designed to create a sense of involvement and motivate employees to identify with and meet organizational goals [133, 134]. HPWP and HIM are derivatives of LM, but not a component of it. However, its relationship to lean and the existence of literature stating a S/E outcome warranted inclusion in this review. Positive outcomes in safety percept
ion (2), safety performance (2), and overall safety and health (1) were found in three articles. No negative or neutral outcomes were found in the literature. These articles are summarized in Table 8.

Table 8: Articles Containing Safety and Ergonomic Outcomes from HPWP and HIM

| Safety/Ergonomic Category | High-Performance Work Practices (HPWP) | High-Involvement Management (HIM) |
|---|---|---|
| Safety & Health Perception, Safety Climate | (+) [133, 135] | |
| Overall Safety, General Health & Well Being | | (+) [134] |
| Safety Records, Accident Rate, Safety Performance | (+) [133] | (+) [134] |

### 2.3.11 Unspecified Lean and TPS Methods or Systems

The largest number of S/E outcomes found in the literature were resulting from unspecified lean methods or systems. The literature contains fifty-five outcomes, most of which are negative. 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. A summary of the S/E outcomes from unspecified lean methods and systems can be found in Table 9.

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).

## 2.4 Discussion of Literature

It is not surprising that some methods resulted in positive S/E outcomes. 5S is focused on shaping and improving working conditions through work organization[136], thus safety is often considered as a direct benefit of 5S implementation [137, 138]. Likewise, a typical goal of a kaizen event is the enhancement of safety in a particular area [139], often implementing 5S methods in this effort [140]. Also, the employee-involvement aspect of kaizen tends to have a positive impact on worker stress by giving workers more job control [72].

A lean factory layout is composed of a group of dissimilar processes operated by

Table 9: Articles Containing Outcomes from Unspecified LM Methods and Systems

| Safety/Ergonomic Category | Unspecified LM Methods/Systems |
| --- | --- |
| Human Factors, Ergonomics, CTD, & WMSD | (-) [141, 142]<br>(+/-) [143]<br>(+) [144, 145] |
| Physical Strain | (-) [143, 146, 147] |
| Stress & Mental Strain | (-) [46, 147-153]<br>(+/-) [154, 155] |
| Psychological/Psychosocial Well-Being | (-) [156]<br>(+/-) [157] |
| Workload, Work Intensity, Exhaustive Work | (-) [147-152, 158-162] |
| Hazards | (-) [143, 150]<br>(+) [163] |
| Safety & Health Perception, Safety Climate | (-) [164, 165]<br>(+) [166] |
| Safety Behavior & Safety Participation | (+/-) [167]<br>(+) [168] |
| Overall Safety, General Health & Well Being | (-) [150, 156, 169]<br>(+/-) [170]<br>(+) [144, 146, 151, 171] |
| Safety Records, Accident Rate, Safety Performance | (-) [160]<br>(+/-) [167, 172, 173]<br>(+) [174-177] |

multifunctional workers, thus repetitive motion is reduced, along with the resultant ergonomic risk [123]. HPWP and HIM are both worker-focused methods of increasing performance through employee involvement and engagement [133, 134], so positive outcomes from these methods could also be expected.

Few S/E outcomes were found that resulted from TPM and TQM, and those results were equally 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 [131] rather than changing how the work is performed, so a small number of outcomes, all with neutral S/E 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 [70]. 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.

JIT is a complex method that requires a high level of self-organization of tasks from the work force, and aims to mitigate idle time[178]. This increase in responsibility and work intensity might explain the large number of negative results from JIT. 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.

## 2.5 Literature Review Summary

In his book "Toyota Production System: An Integrated Approach to Just-in-Time", Monden [18] 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. [4]

describes LM as "humanly fulfilling." And Liker [3], quoting Ohno, stated that "safety is the foundation of all our activities" in reference to the TPS.

However, some literature challenges the assertion that LM is a safe and worker-empowering system. Babson [45] 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 [90], JIT waste reduction efforts have evolved to include increasing worker capacity, while Weingarten, Fan, Lo, and Pagell [89] associated a 1% decrease in worker slack (increase in worker capacity) with a 0.69% increase in workplace injuries.

Just as with the contradicting claims about the design intent of LM concerning worker well-being, the LM related S/E outcomes found in the literature are also contradictory. Our research found 101 articles containing S/E 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 S/E 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 S/E dimensions (Table 10). Such a wide disparity of outcomes in the two most commonly methods found in the literature is a matter to consider when examining the unclear relationship between LM and safety/ergonomics.

In addition to LM methods and S/E outcomes, the detailed findings in Table 11 provide the year, location, industry, sample size, and other details of the included studies that provide direction for future research. What is already apparent, however, is that the relationship between LM and S/E is complex, with the adoption or use of some LM methods affecting S/E differently than others. Ultimately the findings of this review agree with Koukoulaki [179] and Arezes, Dinis-Carvalho, and Alves [51], who stressed the importance of considering individual LM methods and principles, rather than the LM system as a whole, in determining how S/E may be affected.

Table 10: Outcome summary with symbols for negative (●), neutral/offsetting (◐), and positive (○) safety/ergonomic outcomes

| | JIT, Work Pacing, Slack Reduction, Chaku-Chaku | Kanban | 5S | Stand-ardized 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 | 3,0,3 | 0,0,3 | 0,0,2 | 33,9,13 |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Babson (1993) [45] | Automobile assembly | Michigan, USA | Survey & worker's compensation claims | 2,380 workers | Cross-sectional | Just-in-time (JIT) and Kaizen | ↓ | Increased intensity, high workers' compensation claims |
| Rinehart, Huxley, and Robertson (1994) [46] | Automobile assembly | Ontario, Canada | Survey | 2,300 workers | Longitudinal | Comprehensive lean program | ↓ | 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, Jackson, and Parker (1995) [13] | Electronics manufacturing | United Kingdom | Survey | 32 workers | Longitudinal | JIT | ↑↓ | No effect on stress or work intensification. |
| Parker, Myers, and Wall (1995) [146] | 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) [148] | Automobile manufacturing | USA and United Kingdom | Questionnaires | 372 workers in 4 factories | Case study | Comprehensive lean programs | ↓ | Workers perceived lean to be more demanding, both physically and mentally. |
| Jackson and Martin (1996) [106] | Electronics manufacturing | United Kingdom | Survey | 44 workers | Longitudinal | JIT | ↑↓ | JIT had no effect on psychological well-being. |
| Adler, Goldoftas, and Levine (1997) [47] | Automobile assembly | California, USA | Cal-OSHA citations | 4,000 workers (est.) | Longitudinal | JIT and Kaizen | ↓ | Increase in ergonomic injuries, Cal-OSHA citations |
| Lewchuk and Robertson (1997) [75] | Automobile assembly | Canada | Survey | 2,424 workers | Cross-sectional | JIT and Kaizen | ↑↓ | Of two lean plants, one had higher work intensity than traditional plants, one had lower |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Parker and Sprigg (1998) [98] | 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) [158] | Automotive components | Canada | Survey | 1,670 workers, 16 workplaces | Cross-sectional | Comprehensive lean implementation | ↓ | Workers reported faster pace and heavier workload in lean factories, compared to traditional factories |
| Yildirim (1999) [121] | 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) [97] | 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) [99] | Multiple industries | Canada | Telephone survey | 508 workers | Cross-sectional | JIT | ↓ | Negative effect on worker stress |
| Hunter (2001) [123] | 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, Stewart and Yates (2001) [100] | Automobile manufacturing | United Kingdom and Canada | Survey | 2,639 workers | Cross-sectional | WIP reduction, pull systems, JIT | ↓ | Excessive workload, increased stress |
| Anderson-Connolly, Grunberg, Greenberg, and Moore (2002) [149] | Anonymous company | USA | Survey | 1,000 workers | Longitudinal | Comprehensive lean implementation | ↓ | Increased stress and higher work intensity |
| Bruno and Jordan (2002) [73] | Automobile assembly | Illinois, USA | Survey | 1,000 workers | Longitudinal | Kaizen | ↓ | Job eliminations from Kaizen results intensified workload |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Harenstam, Rydbeck, Johansson, Karlqvist, and Wiklund (2002) [159] | Multiple industries | Sweden | Interviews | 208 workers | Case study | General lean | ↓ | Increased workload reported in lean organizations. |
| Parker (2003) [101] | Automobile assembly | United Kingdom | Survey | 368 workers | Longitudinal | WIP reduction, pull system | ↓ | Negative stress and psychological outcomes |
| Brenner, Fairris, and Ruser (2004) [95] | Multiple industries | USA | Survey | 1,848 workers | Cross-sectional | Quality circles and JIT | ↓ | Negative effect on cumulative trauma disorders |
| Schouteten and Benders (2004) [104] | 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) [102] | Multiple industries | Finland | Interviews and questionnaires | 525 workers | Cross-sectional | JIT | ↓ | Increase in stress, particularly for white-collar, maintenance, and material workers |
| Cochrane, Law, and Piercy (2005) [135] | 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, Angelis, Cooper, Faragher, and Gill (2006) [72] | Multiple industries | United Kingdom | Interviews and questionnaires | 1,391 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, Kraemer-Heriaud, Marescaux, and Frimat (2006) [120] | Automobile assembly | France | Questionnaire | 80 workers | Longitudinal | TQM | ↓ | Negative effect on injury rate, strain, and stress |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Mehri (2006) [160] | Automobile assembly | Japan | Interviews and direct observations | 75 affiliated people | Case study | Comprehensive lean program | ↓ | High work intensity and injury rates, along with accident misreporting by the company |
| Velazquez, Munguia, de los Angeles Navarrete, and Zavala (2006) [141] | Various industries; maquiladora manufacturing | Mexico | OSHA program evaluation profile (PEP) | 50 workers | Case study | Comprehensive lean program | ↓ | Multiple negative effects from lean production, including musculoskeletal symptoms. |
| Brown and O'Rourke (2007) [129] | 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) [70] | 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, Moore, Greenberg, and Sikora (2008) [169] | Advanced technology products | USA | Questionnaires and interviews | 525 workers, white & blue collar | Longitudinal | Comprehensive lean program | ↓ | Increase in reported health problems after lean implementation |
| Hunter (2008) [126] | 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, Moore, and Strolle (2008) [171] | Automobile manufacturing | Antwerp, Belgium | Company documentation and interviews | 1 Company, >1,000 workers est. | Longitudinal | Comprehensive lean program | ↑ | Reduction in minor (first aid) accidents after lean implementation, despite doubling of car output per worker |
| Lu (2009) [150] | Garment and electronics manufcturing | Philippines | Questionnaire | 630 workers | Cross-sectional | Comprehensive lean program | ↓ | Intensification of work resulted in stress, new forms of hazard, and occupational illnesses. |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Nikolou-Walker and Lavery (2009) [151] | Engineering | Ireland | Observations, interviews, & statistical analysis | 250 workers | Cross-sectional | Comprehensive lean program | ↑↓ | Lean improved overall safety, but a minority of workers experienced increased workload and stress |
| Saurin and Ferreira (2009) [78] | Farm equipment manufacturing | Brazil | Survey | 67 workers | Case study | Housekeeping (5S) | ↑ | Improvement in perceived safety |
| Womack, Armstrong, and Liker (2009) [108] | 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 scores than traditional plant |
| Bernardo and Sato (2010) [156] | Automobile manufacturing | Brazil | Interviews | 40 workers | Case study | Comprehensive lean program | ↓ | Physical and mental illnesses due to work pressure and work intensification. |
| Brannmark (2010) [180] | Multiple industries | Sweden | Interviews and questionnaires | 123 workers | Case study | Comprehensive lean program | ↑↓ | Increase in workplace safety, but also an increase in stress |
| Wong and Richardson (2010) [143] | Semiconductor manufacturing | Malaysia | Ergonomic assessment | 61 workers | Cross-sectional | Comprehensive lean program | ↑↓ | Lean production line had more reported job risk and eye strain than conventional line, but less reported head and neck pain |
| Edwards, Thye, and Nielsen (2011) [157] | Multiple industries | Denmark | Seminars and surveys | 3 cases, 130 total workers | Longitudinal | Comprehensive lean program | ↑ | 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) [134] | Multiple industries | Finland | Emperical analysis of government data | 3,755 observations | Longitudinal | Lean-based high involvement management (HIM) | ↑ | HIM Practices are positively associated with employee well-being and lower accident rate |
| Enríquez-Díaz, Kotzab, Sytch and Frieling (2012) [91] | Automotive component manufacturing | Germany | Questionnaire | 165 workers | Longitudinal | Chaku-Chaku | ↓ | Increased stress from work intensification |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Shaikh, Cobb, Golightly, Segal and Haslegrave (2012) [105] | Automotive (simulated) | United Kingdom | Questionnaire | 12 participants | Case study | Cycle-time reduction through waste elimination | ↑↓ | Neutral effect on participant stress levels |
| Brannmark and Holden (2013) [71] | 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) [84] | Injection molding | India | Expert assessment | 1 company | Longitudinal | 5S | ↑ | Safety scores improved after 5S implementation. |
| Sujatha and Rao (2013) [144] | Multiple industries | India | Questionnaires | 44 managers and executives | Cross-sectional | Comprehensive lean programs | ↑ | Safety and ergonomics had a positive relationship with lean program success. |
| Tregaskis, Daniels, Glover, Butler, and Meyer (2013) [133] | 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) [164] | Multiple industries | France | Survey | 24,486 employees | Cross-sectional | Comprehensive lean programs | ↓ | Lean practices, as a bundle, have a deleterious effect on employee-perceived health at work. |
| Chan, Chen, Xie, Wei, and Walker (2014) [142] | Automotive assembly | China | Survey | 1,084 employees, 12 factories | Case study | Comprehensive lean programs | ↓ | High prevalence of WMSD related injury. More than 90% of workers over 35 had reported injury. |
| Chiarini and Vagnoni (2014) [66] | 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. |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Cullinane, Bosak, Flood, and Demerouti (2014) [161] | Pharmaceutical manufacturing | Ireland | Survey | 200 workers | Cross-sectional | Increased pace (resulting from various lean improvements) | ↓ | Increase in worker exhaustion |
| Gupta and Jain (2014) [67] | Glass manufacturing | India | Direct observation | 1 company | Longitudinal | Kaizen and 5S | ↑ | Kaizen based 5S improvements improved ergonomics and removed hazards. |
| Khandelwal, Prathik, Kikani, and Ramesh (2014) [69] | Machinery manufacturing | India | IDEEA device | 2 workers | Longitudinal | 5S | ↑ | Less energy consumption after 5S improvements, which had led to stress. |
| Pagell, Dibrell, Veltri, and Maxwell (2014) [111] | 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, Thiriveni Sripriya, and Sathish Kumar (2014) [79] | 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) [85] | Boiler manufacturing | India | Company records | 1 company | Case study | 5S | ↑ | Decrease in accident severity after 5S implementation. |
| Hernandez Lamprea, Camargo Carreno, and Martinez Sanchez (2015) [24] | Automotive components | Colombia | Surveys and direct assessments | 1 company | Case study | 5S | ↑ | Ergonomic, physical, and other hazards were greatly reduced after 5S implementation. |
| Kumar R., and Kumar V. (2015) [167] | Multiple industries | India | Survey | 59 industries | Case study | Comprehensive lean programs | ↑↓ | Reportable accidents, unsafe practices, and behavioral safety were not improved after lean implementation. |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Mohiuddin, Rahman, and Jabar (2015) [174] | Automotive manufacturing | Malaysia | Company safety data | 1 company | Longitudinal | Comprehensive lean program | ↑ | Company experienced a sharp drop in accident rate after lean implementation |
| Wan Mahmood, Yusup, Salleh, and Yusof (2015) [175] | Multiple industries | Malaysia | Questionnaire | 40 managers and staff | Case study | Comprehensive lean program | ↑ | Lean production has a positive correlation with sustainability components, including safety. |
| Zhang (2015) [152] | Automobile manufacturing | China | Ethnographic research | 7 factories | Case study | Comprehensive lean programs | ↓ | Lean systems resulted in intense work pace and high stress. |
| Abeysekera and Illankoon (2016) [60] | 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, Robledo, and Kobi (2016) [170] | Multiple industries | France | Survey | 33 (est.) lean experts | Case study | Comprehensive lean implementation | ↑↓ | Hypothesis that lean had positive safety effects was rejected. |
| Bao, Kapellusch, Merryweather, Thiese, Garg, Hegmann, and Silverstein (2016) [109] | Multiple industries | USA | SI, HAL, TLV, assessments | 1,834 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, Rehman, Case, Masood, and Habib (2016) [131] | 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, R. and Kumar, V. (2016) [168] | Multiple industries | India | Survey | 62 companies | Case study | Comprehensive lean program | ↑ | Lean has a positive impact on employee safety participation. |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Manfredsson (2016) [154] | Textile manufacturing | Sweden | Interviews, observations, & group discussions. | 2 teams, 11 total workers | Case study | Comprehensive lean implementation | ↑↓ | Lean was found to have increased stress in one company, but reduced stress in another. |
| Ramesh and Ravi (2016) [86] | Cutting tool manufacturing | India | Questionnaire | 75 workers | Case study | 5S | ↑ | Significant relationship between 5S implementation and improved safety performance. |
| Resta, Dotti, Gaiardelli, and Boffelli (2016) [94] | 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 reduced risks and reduced stress. |
| Srinivasan, Ikuma, Shakouri, Nahmens, and Harvey (2016) [80] | 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, Mrozowicki, Danford, and Murphy (2016) [147] | Automobile manufacturing | United Kingdom and Poland | Surveys and interviews | 439 workers | Case study | Comprehensive lean program | ↓ | Increased work intensity, higher levels of physical discomfort, stress, and exhaustion after lean introduction. |
| Widyanti and Larutama (2016) [155] | Aerospace manufacturing | Indonesia | Questionnaires and NASA-TLX | 90 workers | Case study | Comprehensive lean implementation | ↑↓ | No significant correlation between lean performance and mental workload. |
| Aziz, Moussa, and Nafee (2017) [163] | Textile manufacturing | Egypt | Direct observation | 2 factories | Case study | Comprehensive lean implementation | ↑ | Lean implementation resulted in a reduction of heat, chemical, and ergonomic hazards. |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Camuffo, De Stefano, and Paolino (2017) [176] | Tire manufacturing | Multiple countries (Europe) | Interviews and observations | 32 production departments in 9 facilities | Cross-sectional | Comprehensive lean program | ↑ | The degree of lean adoption was positively related to a reduction of accidents. |
| Distelhorst, Hainmueller, and Locke (2017) [172] | Apparel manufacturing (Nike) | 11 developing countries | Factory audits | 300 factories | Cross-sectional | Comprehensive lean implementations | ↑↓ | No relationship was found between lean adoption and health and safety standards. |
| Hakansson et al. (2017) [68] | 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) [162] | Consumer-goods manufacturing | China | Survey | 226 frontline managers | Case study | Comprehensive lean implementation | ↓ | Lean-associated role overload was a risk to frontline managers, which relates to exhaustion. |
| Ramesh and Ravi (2017) [166] | Cutting tool manufacturing | India | Questionnaire | 75 workers | Case study | Comprehensive lean implementation | ↑ | 70.6% of workers felt that total employee involvement created a safe workplace. |
| Todorovic and Cupic (2017) [87] | Rubber goods manufacturing | Serbia | Company OHS metrics | 1,179 workers | Case study | 5S | ↑ | Injury frequency and severity showed downward trends after 5S implementation. |
| Wiengarten, Fan, Lo, and Pagell (2017) [89] | Multiple industries | USA | OSHA and COMPUSTAT data | 3,945 companies | Cross-sectional | Slack (waste) reduction | ↓ | Reduction in operational slack increases number of safety violations. |
| Fernandes, Godina, and Matias (2018) [76] | Automobile manufacturing | Europe | Direct observation | 1 work area | Longitudinal | 5S | ↑ | 5S implementation reduced risk of forklift-pedestrian collision by 64%. |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Huo and Boxall (2018) [74] | 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) [96] | 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) [125] | 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) [88] | Automotive parts manufacturing | India | Company safety metrics | 36 manufacturing zones | Case study | 5S and Kaizen | ↑ | Accident frequency and severity improved after 5S, improved further through Kaizen. |
| Ratnayake and Dinosha (2018) [127] | 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) [81] | Multiple industries | India | Questionnaire | 100 companies | Case study | 5S | ↑ | Workplace safety was viewed as “highly improved” after 5S implementation. |
| Adzrie, Chai, Elcy, Joselyn, Mohd-Lair, and Madlan (2019) [83] | Metal fabrication—stainless steel tables | Malaysia | Survey | 30 workers | Longitudinal | 5S | ↑ | Safety initially improved after 5S introduction and continued to improve over time. |
| Beraldin, Danese, and Romano (2019) [107] | 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). |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Bocquet, Dubouloz, and Chakor (2019) [153] | 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, da Silva, Arezes, Dangelino, and Padula (2019) [130] | 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, Boxall, and Cheung (2019) [103] | 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) [82] | 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, Fettermann, Piñeres, and Gaiardelli (2019) [110] | Multiple industries | Brazil | Survey | 144 companies | Cross-sectional | JIT | ↑↓ | Neutral effect on worker health |
| Ulewicz and Lazar (2019) [177] | Metal manufacturing | Poland and Romania | Surveys and public company safety data | 20 companies | Cross-sectional | Comprehensive lean program | ↑ | Companies using lean tools reported fewer critical incidents than industry average and improved further with time. |
| Annamalai, Kumar, and Bagathsingh (2020) [128] | Garment manufacturing | Tamilnadu, India | Questionnaires | 80 workers | Case study | Lean production layout | ↑ | Positive correlation between lean production layout and safety/ergonomics |

Table 11: Details from Safety and Ergonomic Outcomes Found in the Literature

| Article | Industry | Location | Meas. Method | Sample | Study Type | Lean Practice | ↑↓ | Safety and Ergonomic Outcome |
|---|---|---|---|---|---|---|---|---|
| Cierniak-Emerych and Golej (2020) [61] | 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, Baseggio, Panizzolo, and Biazzo (2020) [77] | 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, Jazani, Cudney, and Trucco (2020) [173] | 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) [145] | 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) [165] | Multiple industries | France | Surveys and interviews | 9 companies, 380 workers | Case studies | General lean transformation | ↓ | Negative perceived health effect, mitigated by team learning. |

# Chapter 3 Research Question and Hypotheses

## 3.1 Objective

The literature review in Chapter 2 revealed a need for an experimental approach for analyzing the effects of LM on S/E. Since the literature suggests that each LM principle uniquely affects S/E, a method to test the effects from the adoption level of each LM principle may reveal a more detailed explanation of the overall relationship. While any analyses of the effects of LM components on S/E would not constitute an original method or study, defining the overall LM relationship with S/E through a summary of the relationships from each principle does constitute a unique approach. The use of a survey to assess a company's implementation of lean principles, such as the survey by Huang, Harris, and Loyd [181], could be compared to safety data to determine if the degree of lean culture adoption has any bearing on S/E outcomes. The objective for this research is therefore to characterize the overall effect of LM implementation, as defined by the summation of the implementation of its individual principles, on S/E, through a large-scale cross-sectional study.

## 3.2 Research Question

Lending due credence to the finding of opposing and consistent effects from 5S and JIT, perhaps the most profound take away from the literature review was the under-representation of studies that analyzed the effect of LM Culture, the principle that emphasizes respect for people [18, 181]. The negative effect from JIT on S/E is well described in literature, and this association seems intuitive given the removal of slack in the production flow inherent with JIT implementation [89, 90]. Likewise, the positive effects from the standardization and stability principle, especially the 5S component, are expected and well established in the literature.

What is not well understood is how these principles contribute to the overall S/E effect from LM implementation in aggregate, and how the adoption level of LM culture contributes to the overall relationship. Tortorella, Fettermann, Vergara, and Fries [178] found that the adoption of socio-technical practices that address quality of working life provide an organizational environment for mitigating the potential harm to workers from JIT. Resta, Dotti, Gaiardelli, and Boffelli [94], who reported a rare positive S/E effect from JIT, stated that the companies in their study had implemented countering measures consistent with LM Culture as part of the implementation. These assessments harmonize with LM/TPS pioneers which emphasized that LM Culture and respect for the worker is a critical part of any lean system [2, 4, 18].

In 1970 the Occupational Safety and Health Act, aka the OSH Act, was passed into U.S. law [182], establishing OSHA and NIOSH [183]. One of OSHA's missions is to maintain a reporting and recordkeeping system to monitor job related injuries and illnesses [184]. The data collected from this federally enforced recording and reporting of incidents can be used by companies for proactive motives and by NIOSH for calculating industry rates and conducting research [185, 186]. The incidence rate data from OSHA is publicly available, providing an accessible and reliable measure of a company's S/E condition. While many S/E metrics are used throughout industry, such as safety climate [187] and behavior-based safety (BBS) measures [188], the use of these metrics vary from company to company, and are commonly validated using incidence rates [188-190]. Since an expert assessment of S/E for each manufacturing facility is hardly feasible for a large cross-sectional study, OSHA incidence rates provide the most practical metrics to define S/E in such a study.

Therefore, using these incidence rates to define safety conditions, and LM principle adoption level to define the state of lean, the research question can be expressed as: What is the effect from the implementation of each LM principle on OSHA incidence rates?

### 3.3 Hypotheses

The literature review indicates that many researchers believe that LM implementation does influence S/E from the perspective of the effects from the implementation of the individual principles. While details of the effects from each principle will be explored and discussed, the hypotheses for this study are:

> **$H_0$: Implementation of lean manufacturing principles is independent of OSHA incidence rates.**
>
> **$H_1$: Implementation of lean manufacturing principles is not independent of OSHA incidence rates.**

# Chapter 4 Method Development

In his research, Loyd [191] developed and validated an Employee Perception Survey instrument which demonstrated that non-management employee perception of the state of a lean implementation in a manufacturing environment is a good indicator of the maturity and application of lean principles in that organization. Building on Loyd's work, Huang, Harris, and Loyd [181] developed an improved instrument that utilized a 7-point Likert scale and was validated using company performance metrics. The levels determined by the Huang et al. [181] survey are based upon the LM principles of standardization and stability (5 questions), built-in quality (7 questions), just-in-time (6 questions), and lean culture (9 questions); based on the "Toyota House" model by Loyd [191] (Figure 1). The individual statements used to define adoption level in these categories are shown in Table 12. Organization of this survey instrument allows for unique assessment of each category, thus up to 4 independent variables can be defined based on each LM principle. Therefore, the use of the Huang et al. [181] lean-perception survey

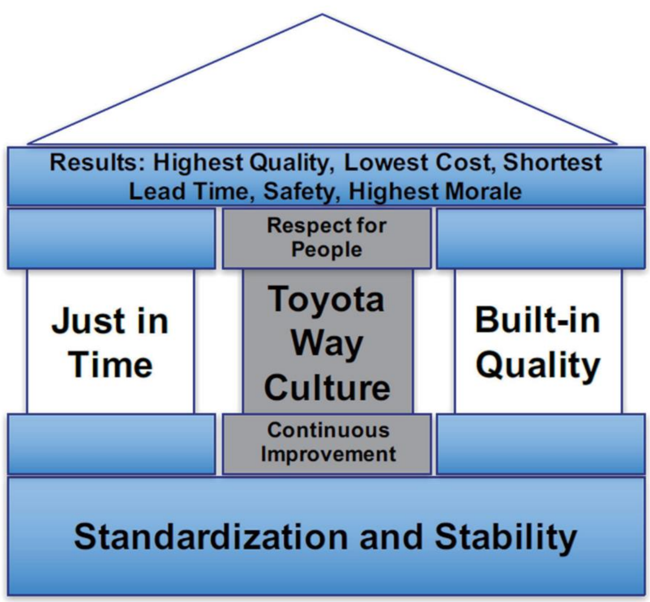



Figure 1: TPS-TW House Model by Loyd [191].

instrument is the chosen technique for defining independent variables in this study.

OSHA requires businesses with more than 10 employees to complete and submit annual logs (OSHA Form 300) of workplace injuries and illnesses that meet the definition of recordable

Table 12: Survey Statements to be Rated on a 7-point Likert Scale.

| **Construct** | **#** | **Statement to be Rated** |
|---|---|---|
| Standardization and Stability | S1 | My company has a well-defined system for workplace organization. |
| | S2 | The best way to do my job is clearly defined and standardized. |
| | S3 | A specific training method is used to introduce, progress, and cross-train employees on their jobs. |
| | S4 | In my workspace, normal operating conditions—such as production status, tool and material locations, and equipment status—are visually obvious. |
| | S5 | My company has a well-defined system to measure process downtime. |
| Quality | Q1 | My company has well-defined processes and procedures to identify defects as they happen at the process. |
| | Q2 | Defect rates are accurately measured at my process. |
| | Q3 | My company seeks to fix problems at the root cause level. |
| | Q4 | When mistakes or defects happen, there is a well-defined system to provide feedback to the source of the mistake. |
| | Q5 | Employees at my company are trained to use a well-defined process to solve problems. |
| | Q6 | My company views problems as opportunities and we stop and learn from them. |
| | Q7 | Effective error-proofing techniques are used at my company. |
| Just-in-Time | J1 | My company seeks to eliminate or reduce batching and work-in-process inventory (WIP). |
| | J2 | Our facility layout allows for work to flow easily from process to process. |
| | J3 | Work in my company is well balanced to meet a specific daily goal. |
| | J4 | Parts are delivered to the production line in the quantities that are needed, when they are needed. |
| | J5 | Work is always scheduled visually based on the next process's needs. |
| | J6 | My company aggressively seeks to reduce inventory. |
| Lean Culture | C1 | I know which steps in my job are value-added or non-value-added. |
| | C2 | Decisions at my company are always based on relevant facts and data. |
| | C3 | Management at my company treats me with respect and I feel I can safely express my opinions. |
| | C4 | I understand my company's strategic vision and mission. |
| | C5 | My company values ideas for improvement from all employees. |
| | C6 | My company values knowledge, skills, and abilities from all employees. |
| | C7 | Teamwork is practiced at my company; everyone is expected and willing to help and hold each other accountable. |
| | C8 | My manager actively works with me to improve my process. |
| | C9 | My company provides good opportunities for my growth and development. |

injury [184]. OSHA uses this data to compile statistics, which include the core facility metrics of total case rate (TCR), cases requiring days away, work restriction, or transfer (DART), and cases requiring days away from work due to injury or illness (DAFWII). The Bureau of Labor Statistics (BLS) also utilizes this data to provide annual counts and rates by industry, categorized by the North American Industry Classification System (NAICS) [192].

Different industries experience different average incidence rates, therefore the use of TCR, DART, and DAFWII rates as dependent variables in a cross-sectional multiple-facility analysis could yield unreliable results due to this confounding industry variance. However, since both incidence rates per facility and per industry are publicly available data through OSHA and BLS respectively, each facility rate can be normalized to the average rate from the industry in which they are classified.

Therefore, the decision is that the dependent variables be constituted of normalized incidence rates, or "scores", for each facility based on how well it is performing within its own industry, providing a more reliable metric to be used in effect analyses. Statistical methods can then be performed by using the survey-defined LM scores as the independent variables and normalized TCR, DART, and DAFWII scores as the dependent variables.

**4.1 Special Considerations when using Likert Point Scales**

Depending on the study design, two types of data can be generated when using a Likert point scale for survey responses: Likert-type data, and Likert-scale data. Likert-type data is generated when the responses for a single question or statement are examined individually [193]. Likert-type data is considered ordinal, thus parametric tests like regression and SEM are not suitable for analysis on the data set [194]. Also, any overall assessments from such single-question Likert responses must be calculated by median or mode rather than by mean [195, 196].

Likert-scale data is generated when the responses from a group of questions define a latent variable or “composite score” [195, 196]. This composite score can be calculated by either summing or averaging the responses from each statement in that category for each completed survey [193]. Therefore, each survey response will generate a composite score for each latent variable that the survey is designed to measure. This Likert-scale data can be treated as interval data, thus parametric statistical testing can be applied. The Huang et al. [181] survey is designed to define composite scores, or constructs, for each LM principle, thus the data in this study can be treated as Likert-scale, or interval, data (Table 12).

**4.2 Defining the Independent Variables: LM Principle Adoption Scores**

The Huang et al. [181] survey instrument presents each participant with a 7-point Likert point scale to rate their agreement with each presented statement (Table 12). The possible responses range from “strongly disagree” to “strongly agree”, with corresponding rating scores from 1 to 7, respectively (Table 13). A mean of the response ratings in each category defines the composite principle score for each survey response. For example, if a participant responded with ratings of 4, 5, 4, 5, 5 for the 5 questions in the standardization/stability category, the score for that category would be calculated as 23÷5, or 4.6, for that survey response [197].

Table 13: Rating Scale for Survey Responses

| Rating | Description |
|---|---|
| 1 | Strongly Disagree |
| 2 | Disagree |
| 3 | Somewhat Disagree |
| 4 | Neither Agree nor Disagree |
| 5 | Somewhat Agree |
| 6 | Agree |
| 7 | Strongly Agree |

To assess the standardization/stability adoption level for a facility, the standardization and stability scores from all survey responses associated with that facility would be averaged. This same method can be used to assess JIT, built-in quality, and LM culture in defining individual principle scores and facility averages for those principles. The review by Brawner et al. [198] did not suggest a likely association between built-in quality and safety/ergonomic outcomes, however the possibility that this principle might constitute a suppressor variable [199, 200] or other indirect effect warrants its inclusion in the data collection and subsequent analysis.

### 4.3 Defining the Dependent Variables: Safety Scores

As with the lean scores, the goal in defining S/E scores is to develop a metric that represents the degree of safety that exists in each workplace. The development of a safety score based on the number of safety incidents experienced within a given facility provides a reliable view of the safety outcomes of an organization, as the defined metric is based on actual events. The organizational injury and illness data publicly available through OSHA include the values needed to calculate these safety incidence rates for most manufacturing facilities in the US. The values provided include the total hours worked (H), total number of cases requiring days away from work (X), total number of cases requiring job transfer or restriction (Y), and other recordable cases (Z). The NIOSH formulas for calculating TCR, DART, and DAFWII from these values are shown in Figure 2 [201].

The BLS publishes industry standard TCR, DART, and DAFWII rates per industry based on the North American Industry Classification System (NAICS). These incidence rates vary significantly from industry to industry. For example, motor vehicle parts manufacturing, NAICS #336300, had an industry average TCR of 3.4 cases per 100 full-time workers in 2019; while aerospace product and parts manufacturing, NAICS #336400, had a TCR of 2.0 cases per 100

$$TCR_C = \frac{(H + I + J) \times 200{,}000}{N}$$

$$DART_C = \frac{(H + I) \times 200{,}000}{N}$$

$$DAFWII_C = \frac{H \times 200{,}000}{N}$$

$TCR_C = Company\ Total\ Case\ Rate$
$DAFWII_C = Company\ Rate\ of\ Cases\ Requiring\ Days\ Away\ from\ Work$
$DART_C = Company\ Rate\ of\ Cases\ Requiring\ Job\ Transfer\ or\ Restriction$

$H = Total\ Number\ of\ Cases\ Requiring\ Days\ Away\ from\ Work$
$I = Total\ Number\ of\ Cases\ Requiring\ Job\ Transfer\ or\ Restriction$
$\mathrm{J} = \text{Total Other Recordable Cases}$
$N = Total\ Hours\ Worked$

Figure 2: Equations for Calculating Dependent Variable Inputs

full-time workers that same year [202].

To normalize the dependent variables and correct for differences in industry average incidence rates, company TCR is subtracted from industry TCR to determine the company TCR score. For example, if a company has a TCR of 5.5 cases per 100 workers per year, and the associated industry average TCR is 4.5 cases per year, then the company score would be -1.0. This would indicate that the company is performing worse than its industry by 1 case per 100 workers. Using this equation, a positive score indicates that the company is performing favorably, while a negative score indicates that the company is performing unfavorably. The same method is used to determine DART and DAFWII scores (Figure 3).

**4.4 Pilot Study**

To test the experimental method for this research [203], a pilot study was performed in a

$$\text{TCR Score} = TCR_I - TCR_C$$
$$\text{DAFWII Score} = \text{DAFWII}_I - \text{DAFWII}_C$$
$$\text{DART Score} = \text{DART}_I - \text{DART}_C$$

$$TCR_C = Company\ TCR$$
$$\text{DAFWII}_C = Company\ DAFWII$$
$$\text{DART}_C = Company\ DART$$

$$TCR_I = BLS\ Industry\ Average\ TCR\ Rate$$
$$\text{DAFWII}_I = BLS\ Industry\ Average\ DAFWII\ Rate$$
$$\text{DART}_I = BLS\ Industry\ Average\ DART\ Rate$$

Figure 3: Equations for Calculating Dependent Variables

manufacturing company with between 301 and 500 employees. Pilot studies are conducted for the purpose of examining the feasibility of a proposed study and to ensure the analysis approach is sound, rather than checking any statistical significance from the results and making research conclusions [204]. The advantages of conducting a pilot study is that it might give advanced warning about where the main research project could fail, where research protocols may not be followed, or whether proposed methods or instruments are inappropriate or too complicated [205].

Prior to any surveying activity, a request was sent to the institutional review board (IRB) at Auburn University for permission to execute the research utilizing the Huang et al. survey instrument [181]. Permission was granted on August 11, 2021, to proceed with survey deployment. The Huang et al. [181] employee-perception survey was replicated in Qualtrics, the chosen survey distribution service, and permission was granted by the target company to conduct the surveying activities. The link to the survey was distributed electronically by a manager of the company to 33 participants, either through email (21) or text (12).

### 4.5 Determination of Statistical Testing Methods

The data collection method defined the independent variables of standardization and stability, built-in quality, JIT, and LM culture; along with the dependent variables of TCRsc, DARTsc, and DAFWIIsc (Table 14). These data can be examined both at a facility level and at an individual level, depending on the desired statistical test, and whether the requisite sample size was achieved to use facilities as the study sample. Both levels of examination can be conducted using regression analysis and structural equation modeling (SEM), however the large sample size required for SEM is more easily achieved using individual level analysis.

#### 4.5.1 Regression Analysis

Linear regression analysis, usually referred to as "regression" or "regression analysis", estimates the relationship between a response variable and either a single explanatory variable (simple regression) or multiple explanatory variables (multiple regression) [206, 207]. The first proposed statistical test for this study is regression analysis using manufacturing facility data as the study sample. To determine the scores for each facility, the survey response sample size for each facility must be large enough to satisfy the desired confidence level and confidence interval in defining the four independent variables. This minimum sample size for each facility can be

Table 14: Variables Defined by Data Collection Methods.

| Independent Variables (Lean) | Dependent Variables (Safety) |
|---|---|
| Standardization and Stability<br>Built-in Quality<br>Just-in-Time<br>Culture<br>Overall Lean | Normalized Total Case Rate (TCRsc)<br>Normalized Rate of Days Away, Restricted, or Transferred (DARTsc)<br>Normalized Rate of Days Away from Work due to Injury or Illness (DAFWIIsc) |

calculated by methods such as those proposed by Israel [208]. For each facility, the independent variables would consist of an average of category scores captured from survey responses, while the dependent variable is already a single value based on each individual facility. Since multiple independent variables have been defined, multiple regression analysis can be performed using a variety of independent and dependent variable combinations.

### 4.5.2 Structural Equation Modeling (SEM)

SEM is a collection of statistical techniques that allow a set of complex relationships between one or more independent variables and one or more dependent variables to be examined, with error removed leaving only common variance [209]. The flexibility inherent in SEM analysis allows for a variety of relationships between constructs to be examined. For example, the 27 observed variables from the survey can be used to define 4 latent variables of standardization and stability (S), built-in quality (Q), JIT (J), and lean culture (C). These 4 latent variables can then be used to define a second order "lean" construct, and the relationship between this construct and any of the dependent variables can be examined. A visual SEM representation of this example can be found in Figure 4. Likewise, any of the 4 latent variables defined by the survey can be used to examine the relationship of each individual lean construct with any of the 3 dependent variables (Figure 5).

### 4.5.3 Statistical Method Discussion

The dependent variables are represented by OSHA injury records and BLS industry averages, both publicly available metrics. Therefore, a straightforward method exists for defining these variables using integrous data. Brawner et al. [198] and Koukoulaki [179] found that the effect of lean on S/E may be explained by the unique effects of lean components and methods. The 4 principles measured by the Huang et al. [31] employee perception survey provide a method of

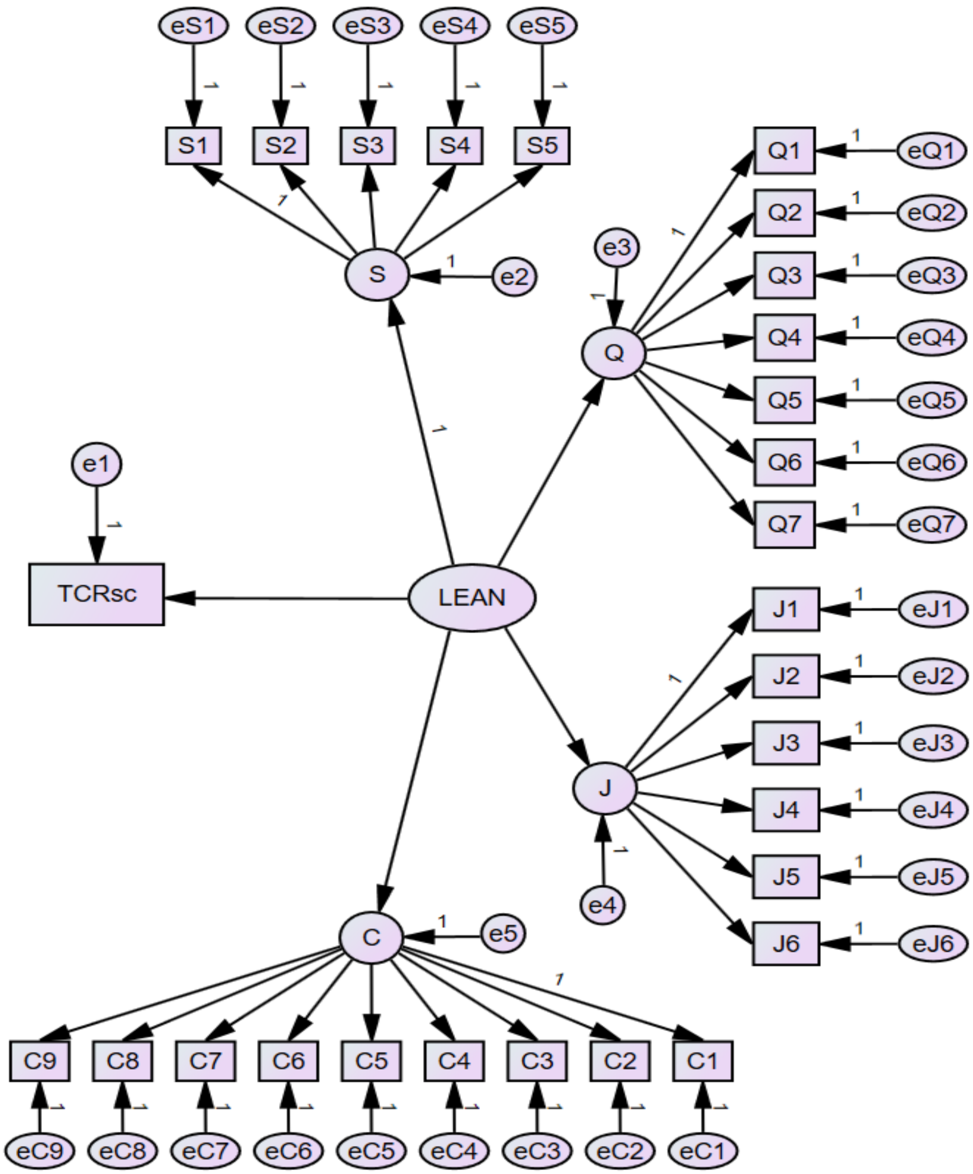



Figure 4: Structural Equation Model to Examine the Association between Lean and TCRsc.

defining independent variables that aligns with these findings. For example, the literature suggests that JIT has a unique and negative effect on S/E, and the employee-perceived adoption level of this specific principle is directly measured by the survey. Also, the adoption level of the standardization and stability principle is measured by the survey, and the questions that define this level relate heavily to 5S and standardized work. While the literature indicates that

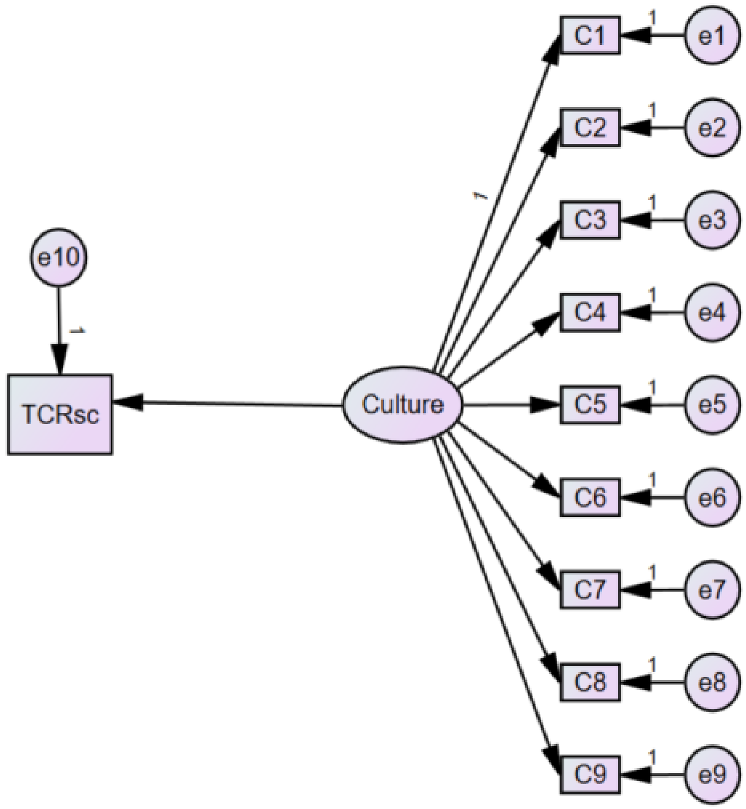



Figure 5: Structural equation model to examine the relationship between culture and TCRsc.

standardized work has neutral effects on S/E, 5S is a method that has been overwhelmingly shown in the literature to have positive S/E effects. Thus, a sound method has been established to examine the relationship between lean principles and safety/ergonomics on a large scale, heeding the literary nuances of this relationship.

**4.6 Summary of Method Design**

The literature pertaining to the effects of lean manufacturing on safety/ergonomics does not provide a clear understanding or representation of those effects. Most studies on the topic are isolated to one facility or a small group of facilities, providing an inadequate sample size to determine the overall relationship. Also, lean as a causal factor is often treated as a binary variable, i.e., either present or absent, disregarding the level of lean adoption within the studied organizations. Furthermore, most studies did not consider the presence or adoption levels of individual lean methods or principles as specific causal factors, while Brawner et al. [198] found that these factors uniquely affect S/E outcomes in studies in which they are considered. Additionally, the definition of the safety/ergonomic outcome in most studies was based on an arbitrary safety assessment rather than a measured metric.

The methodology detailed in this dissertation is designed to overcome these limitations. The Huang et al. [181] survey instrument measures the adoption level of individual lean principles within a manufacturing facility, and can be easily deployed to multiple companies through the use of a web-based surveying service such as Qualtrics, Pollfish, or Survey Monkey. The public availability of incidence rates for individual facilities through OSHA provides a sound and accessible definition for the dependent variable of safety/ergonomic outcomes. Industry average incidence rates are publicly available from the BLS which can be used to normalize the OSHA rates to a facility's respective industry, permitting a cross-sectional study of many facilities across multiple industries.

The method described here is specifically designed for large-scale cross-sectional examination of the effect of lean manufacturing on occupational S/E. The use of web-based surveying and the availability of both facility-specific and industry standard incidence rates allows for the collection of large amounts of data in a short period of time. As it is important for manufacturers to improve competitiveness in a world marketplace, the implementation of Lean Manufacturing is a commonly used approach. However, if this method of continuous improvement puts workers into potentially poor safety situations, is it really improvement? The eventual goal in developing this methodology is to conclusively answer the main research question; what is the relationship between lean manufacturing and safety/ergonomics? Is it Lean

Manufacturing that is the culprit for increased safety concerns, or is it the manner in which the Lean Manufacturing principles and tools are implemented?

# Chapter 5 Results

## 5.1 Results from the Pilot Study

The overall response rate from the survey was 67% (22 out of 33), however one survey had no logged responses, and another had logged the same answer for all questions. These two responses were disregarded, reducing the overall useful responses to 20. The Qualtrics service measures the length of time taken to complete each survey, which was shown to be less than 5 minutes by 4 respondents (20%), between 5-10 minutes by 9 respondents (45%), between 10-15 minutes by 2 respondents (10%), and more than 15 minutes by the remaining 5 respondents (25%). According to feedback from these participants, the survey was straightforward and simple to navigate regardless of the distribution method. No negative feedback was received, however many participants expressed concerns about data privacy prompting reassurance from the manager who distributed the survey.

When using Likert scales, it is important to calculate and report Cronbach's alpha coefficient to determine internal consistency reliability [210]. While the Huang et al. [181] survey is a validated instrument [204], Cronbach's alpha coefficient was nevertheless calculated for each construct featured in the survey instrument, based on the responses from the pilot survey. The Cronbach's alpha calculation measures the correlation between items in the same scale, with values above 0.7 considered appropriate for exploratory research [191, 211, 212]. Each construct demonstrated a Cronbach's alpha coefficient greater than 0.8 (Table 15), demonstrating a good internal consistency of the items in the scale.

Common method bias refers to the variance in responses of a survey due to the measurement method or instrument itself, rather than the predilections of the respondents, and is a common occurrence in survey-based research [204, 213]. The Harman single factor test is a

Table 15: Cronbach's Alpha Coefficients from the Pilot Study

| Construct | Cronbach's Alpha | Status |
|---|---|---|
| Standardization and Stability | 0.883 | Good |
| Built-in Quality | 0.855 | Good |
| Just-in-Time | 0.868 | Good |
| Culture | 0.896 | Good |

well-established and popular method [214] and was therefore chosen as the technique to check for common method bias [213]. If one single factor would account for over 50% of the covariance based on the Principal Axis Factoring (PAF) extraction method, then it implies that a significant common method bias is present [204]. The IBM SPSS Statistics Version 28 software program was used to conduct Harman's single factor test using PAF as the extraction method on the data of the pilot study. The result shows that the largest factor accounts for 42.09% of the overall covariance, which is better than the threshold value of 50%. Therefore, the result of the initial Harman single factor test shows that significant common method bias is not present for the survey instrument.

Analysis of the pilot study data strengthened confidence in the validation of the Huang et al. [181] survey instrument. While a sample size of only one company is insufficient for statistical analysis on relationships, it is interesting that a company operating with above average safety rates had below average lean scores for all 4 principles (Table 16). The full study will tell whether this finding provides a preview of the relationship between LM and S/E, or whether this case would be an outlier in a large-scale analysis.

**5.2 Full Study Data Collection**

The target population for survey distribution was comprised of companies within the supply chain of the principal investigator's employer. In addition to the IRB approval, a permission

Table 16: Lean Average Scores and Safety Scores from the Pilot Survey.

| Standardization & Stability | Quality | Just-in-Time | Lean Culture | TCRsc | DARTsc | DAFWIIsc |
|---|---|---|---|---|---|---|
| 3.70 | 3.66 | 3.43 | 3.91 | +2.58 | +1.18 | +0.21 |

letter was granted by the employer company to distribute the survey. The first survey invitations were sent out via email. Invitations were sent only to facilities in the manufacturing sector that contained publicized OSHA safety rates. A total of 337 manufacturing facilities received invitations. To expand the survey distribution further, a revision to the IRB request was submitted requesting the solicitation of companies from professional company contacts. This modification was approved, and an additional 24 facilities were invited to participate in the survey. A total of 361 facilities received invitations.

Overall, 621 responses were received from 37 manufacturing facilities. A total of 24 survey responses with all blank answers or all the same answers were removed, reducing the response total to 597. Since the survey instrument was primarily designed to capture front-line employee perception, all submissions except those from front-line employees were excluded, resulting in 378 usable submissions from 17 facilities.

**5.3 Organization of Data for Analysis**

The first technique used to organize the data was to calculate variables at the facility level. Each facility has a unique value for each of the three dependent variables through OSHA and BLS. To create a single facility-level value for each of the independent variables (S&S, Quality, JIT, and Culture) answers from each lean category were averaged for every survey response, constituting an individual lean principle score. Then these individual lean category scores will be averaged for all survey responses from each specific facility which will establish four lean category scores attributed to each facility. The survey invitation sent to each establishment contained a facility-specific link, which associated each employee response to their employer facility through a facility code.

To attain meaningful facility-level lean scores, a proper sample size had to be achieved within a facility for it to be considered in the sample population. The method to calculate minimum sample size per company is based on Israel [208], with the goal of reaching a 90% confidence level. Overall, 13 facilities reached an adequate sample size for facility-level analysis. The population used in this sample size calculation was based on the population of front-line employees at each facility. Establishments with adequate sample size for facility-level analysis are marked in Table 17.

The second way the data would be organized was at the individual response level. Each valid survey response would have the three dependent variables (TCRsc, DARTsc, and DAFWIIsc) added to their survey response that reflected the scores from their employer facility. Since this data would strictly be used to test the relationship between employee perception of LM principle adoption and the incidence rates in each employee's workplace, an adequate sample size per facility was not required. Rather, each valid survey response was used in the data analysis. This organization and analysis method replicates those of Conti et al. (2006), who studied the effect of lean production on worker job stress [72].

**5.4 Construction of the Data Set**

Before conducting exploratory or statistical analysis and hypothesis testing, the data itself was inspected for outliers, missing data, and normal data distribution. An inadequacy in any of these categories could yield unreliable outcomes or, in the case of missing data and regression

Table 17: Summary of Lean Scores from Survey Responses and Facility Safety Scores

| Facility # | Facility Code | # Front Line | Sample Req. | # Submitted | Adeq. Sample? | S&S Average | Quality Avg. | JIT Average | Culture Avg. | TCR Score | DART Score | DAFWII Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 121 | 15 | 12 | 1 | N | 6.00 | 6.86 | 6.33 | 7.00 | -0.78 | -2.08 | -2.48 |
| 2 | 137 | 10 | 9 | 1 | N | 7.00 | 6.86 | 6.50 | 7.00 | 3.40 | 2.10 | 1.20 |
| 3 | 400 | 19 | 15 | 17 | Y | 5.28 | 4.79 | 4.82 | 5.69 | 3.00 | 2.10 | 1.30 |
| 4 | 401 | 16 | 13 | 21 | Y | 5.07 | 5.23 | 4.83 | 5.22 | 3.00 | 2.10 | 1.30 |
| 5 | 402 | 51 | 29 | 15 | N | 4.18 | 4.24 | 4.63 | 4.09 | 1.15 | 0.25 | 1.30 |
| 6 | 403 | 73 | 35 | 43 | Y | 4.72 | 4.81 | 4.90 | 4.88 | -1.45 | -0.87 | -0.09 |
| 7 | 404 | 15 | 12 | 16 | Y | 4.99 | 4.53 | 4.86 | 5.01 | 2.40 | 1.60 | 0.80 |
| 8 | 405 | 19 | 15 | 21 | Y | 4.42 | 4.37 | 4.32 | 4.49 | 1.48 | 2.10 | 0.90 |
| 9 | 406 | 158 | 47 | 48 | Y | 5.09 | 4.72 | 4.86 | 4.43 | -1.91 | -1.06 | 0.47 |
| 10 | 407 | 12 | 10 | 13 | Y | 5.42 | 5.32 | 5.46 | 6.02 | 2.40 | 1.60 | 0.80 |
| 11 | 408 | 9 | 8 | 9 | Y | 5.60 | 5.33 | 5.19 | 5.90 | 2.40 | 1.60 | 0.80 |
| 12 | 409 | 153 | 47 | 63 | Y | 4.71 | 4.63 | 4.67 | 4.57 | 2.58 | 1.18 | 0.21 |
| 13 | 410 | 12 | 10 | 12 | Y | 5.27 | 5.11 | 5.60 | 5.72 | 1.40 | 0.80 | 0.50 |
| 14 | 411 | 18 | 14 | 17 | Y | 5.46 | 5.32 | 5.23 | 5.50 | 1.00 | 0.50 | 0.30 |
| 15 | 412 | 25 | 18 | 23 | Y | 5.37 | 5.37 | 5.31 | 5.59 | -5.37 | -2.49 | -2.89 |
| 16 | 425 | 275 | 54 | 56 | Y | 4.73 | 4.33 | 4.77 | 4.32 | 5.85 | 4.39 | 3.29 |
| 17 | 501 | 29 | 20 | 2 | N | 5.50 | 5.00 | 4.83 | 5.72 | 1.80 | 1.10 | 0.70 |

analysis, an inability to conduct statistical testing at all. IBM SPSS version 28 software was used for normality and outlier detection.

### 5.4.1 Outlier Data

Two of the seventeen facilities contained questionable values for the dependent variable. Facility #15 (Table 17) contained extremely low case-rate scores, while facility #16 had extremely high scores. A box plot of TCRsc values confirmed their status as outliers (Figure 6). Additionally, these two facilities were the only sites that principal investigator recruited survey participants in-person through persuasion, which calls into question the reliability of the LM survey data from these two companies. Reluctant sample persons, successfully brought into the respondent pool through persuasive efforts, may provide data filled with measurement error [215-217].

Since the independent variables for these two facilities were of questionable reliability, and the dependent variables were the most extreme high and low outliers, these two companies were excluded from further analysis. While other, less-extreme outliers were identified for both independent and dependent variables, data removal was limited to only these two extreme cases, with the caveat that the data set to be examined still contains outlier data. These data points were removed for both facility-level and individual-level analysis. After removing these two outliers,

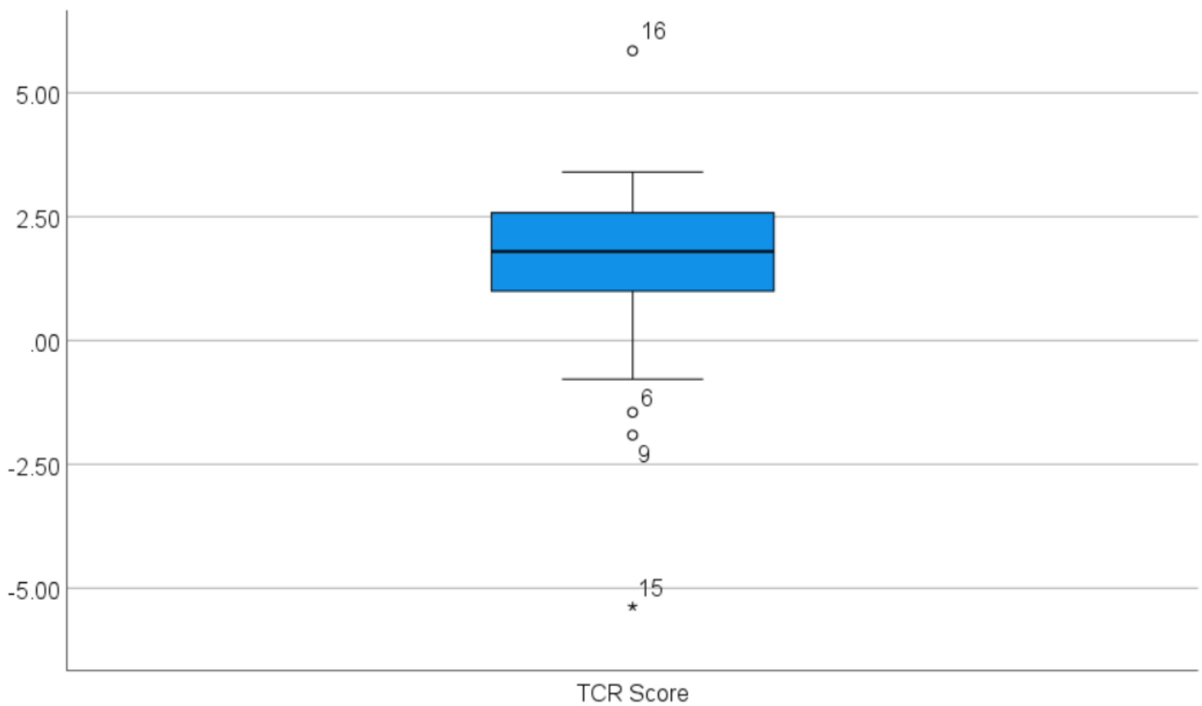



Figure 6: Boxplot of Facility TCRsc

299 front-line responses from 15 facilities remained. The minimum sample size for facility-level analysis had been achieved for these two removed facilities, therefore the sample population of establishments for facility-level analysis was reduced to 11. These removed companies are highlighted in Table 17.

### 5.4.2 Blank Entries in Survey Responses

While initial screening of survey data removed those responses with all blank or all matching entries, those with some blank entries were kept in the data set. Missing data values are problematic when using regression and SEM, however the survey responses containing blanks would only be used where the analysis method did not consider the blank entries. For example, a survey response with blank entries in the Culture section would not be used in any analysis where Culture was considered but may be used in individual-level analyses specific to JIT or S&S. Since the data loss from blank entries was small, the need for methods such as imputation or maximum likelihood [218] would not be necessary to fill-in the missing values. The resulting sample sizes for each potential analysis method can be found in Table 18.

## 5.5 Exploratory Data Analysis

The literature review in Chapter 2 established several literary narratives about the relationship between LM and S/E. The use of JIT, a component method and principle of lean, was

Table 18: Sample Sizes for Testing after Removal of Data

| **Analysis Method** | **N** |
|---|---|
| Exploratory and Parametric Analysis on Facility-Level Data | 11 |
| Exploratory, Parametric, and Non-Parametric Analysis on Individual Data | 271 |
| Parametric and Non-Parametric Analysis on Individual Data—Quality Only | 282 |
| Parametric and Non-Parametric Analysis on Individual Data—JIT Only | 284 |
| Parametric and Non-Parametric Analysis on Individual Data—Culture Only | 281 |
| Parametric and Non-Parametric Analysis on Individual Data—S&S Only | 289 |

associated with overwhelmingly negative safety outcomes in the literature, while use of the 5S method was associated with almost exclusively positive outcomes. Results were more balanced concerning the other examined LM methods, however the use of lean culture, the principle that prioritizes respect for the worker, had very little representation and no outcomes in the found literature. To investigate these reported relationships, several exploratory methods were employed to examine how adoption levels of the four LM principles, defined by the survey, are related with safety. For the exploratory analysis only TCRsc will be examined, as both DARTsc and DAFWIIsc are subsets of TCRsc. Central tendencies for participant's individual survey statement ratings can be found in Appendix C.

### 5.5.1 General Data Observations

Each facility with sufficient sample size contained an average score above 4 for all four LM principle adoption levels, indicating that these facilities had achieved some level of LM adoption in these categories (Figure 7). These indications are not necessarily attributable to any official LM implementation at these facilities but are attributable to practices consistent with LM. These facilities also contained mostly favorable safety rates, with only 2 of the 11 facilities containing incidence rates worse than their respective industry average (Figure 8). The fact that the data contained facilities with positively perceived LM adoption levels and mostly above average safety performance is mildly suggestive of a positive relationship between LM and safety.

### 5.5.2 Analysis by Ranking

Using the 11 facilities that passed the screening for outliers and sample size, a ranking table was created to examine how these facilities' independent/dependent variables compared within the group. In this table, a rank of 1 indicates that a facility has the highest (most favorable) TCRsc score, or the highest level of adoption in the LM categories, while a rank of 11 indicates the least

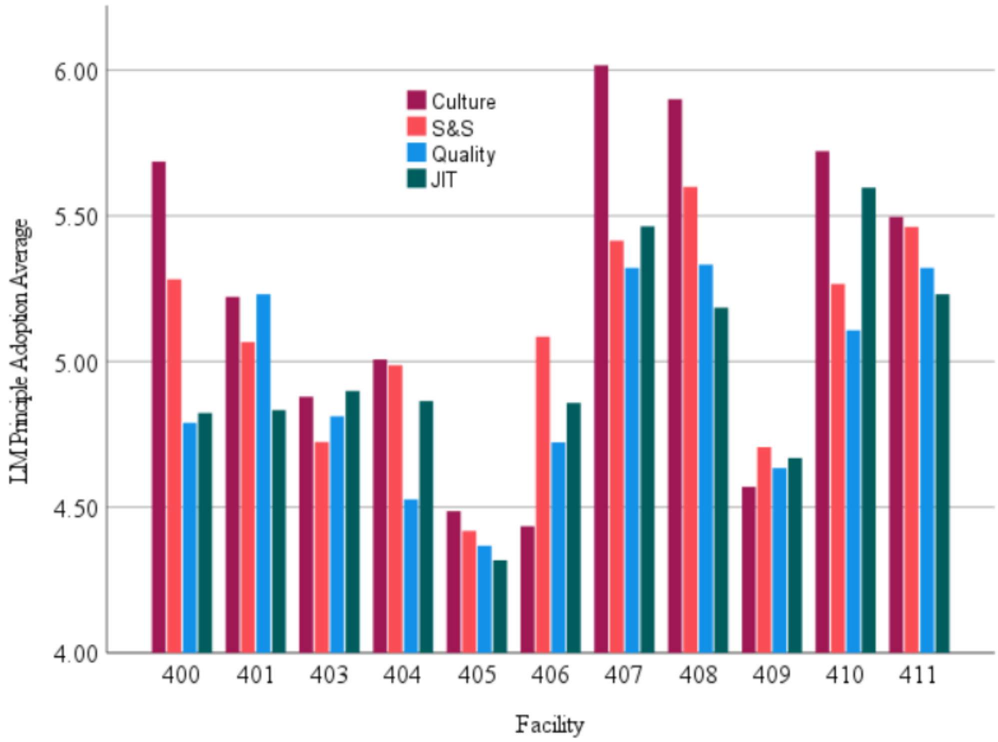



Figure 7: Average LM Principle Adoption Levels per Facility

favorable TCRsc and lowest level of LM principle adoption. Facilities were sorted by TCRsc rank, and the four independent variables were listed in columns in accordance with their corresponding facility (Table 19). While the data set does not provide conclusive information at-a-glance, several meaningful insights were gained through careful examination. Of the 11 facilities that were screened for outliers and sample size, some of the facilities with high adoption levels for JIT adoption ranked as some of the least favorable in TCRsc, and vice-versa. The 3 most favorably ranked facilities in TCRsc ranked in the lowest 4 in JIT adoption levels, which may be an indication that higher levels of JIT adoption are negatively associated with TCRsc, consistent with the literature review findings. Conversely, the facility with the least favorable TCRsc ranking was also the facility with the lowest perceived Culture adoption level, while the facility with the most favorable TCRsc ranked 4$^{th}$ in perceived Culture adoption,

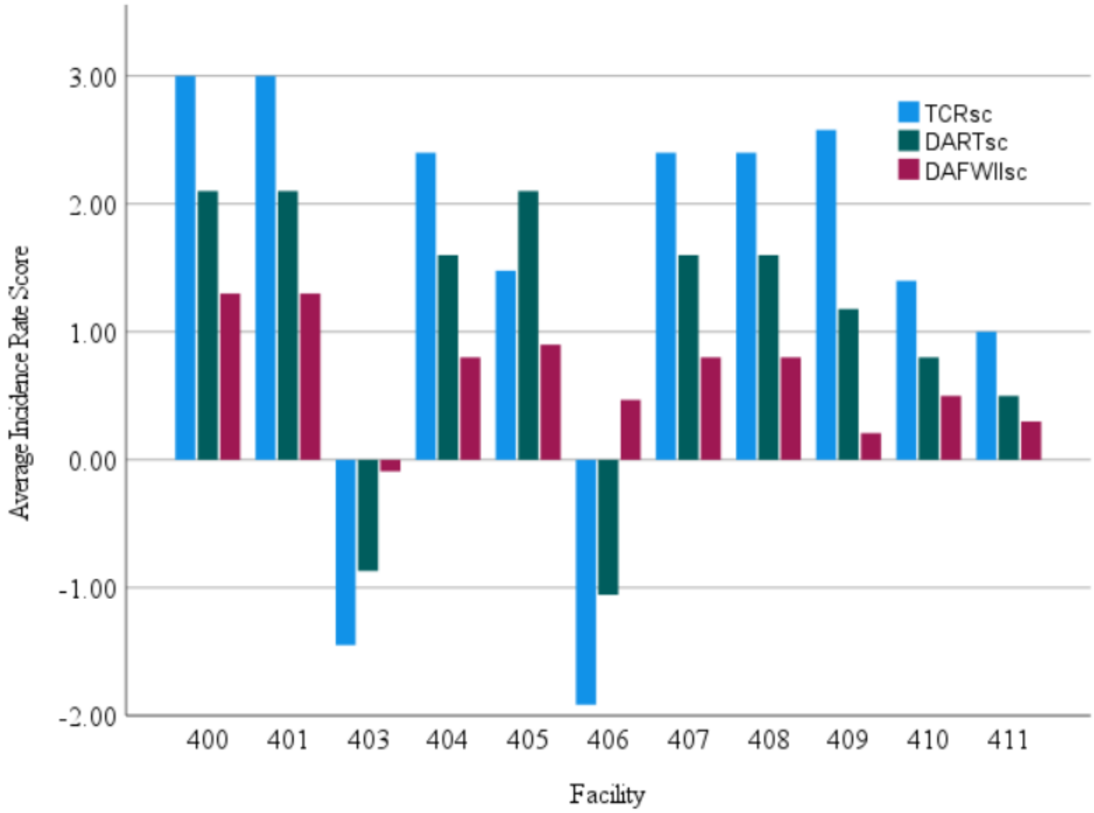



Figure 8: Incidence Rate Scores per Facility

implying some level of positive correlation between the two. No such indications were found with either Quality or S&S.

These observations to some extent support the narrative from the literature review that JIT has a negative effect on S/E. However, this same analysis method did not support the implication that 5S, a component of S&S, has a positive effect on S/E. The findings regarding LM Culture were noteworthy, as no inferences had been established from the literature review concerning this relationship, however the data implies that a positive correlation is plausible given the "respect for humanity" aspect of this LM principle [18].

### 5.5.3 Box Plot Analysis

To further examine the data, a box plot chart was created for the principles of S&S, JIT, and

Table 19: Rank Comparison of Variables by Facility

| Facility | TCRsc | TCRsc Rank | S&S Rank | Quality Rank | JIT Rank | Culture Rank |
|---|---|---|---|---|---|---|
| 400 | 3.00 | 1 | 4 | 7 | 9 | 4 |
| 401 | 3.00 | 1 | 7 | 4 | 8 | 6 |
| 409 | 2.58 | 3 | 10 | 9 | 10 | 9 |
| 408 | 2.40 | 4 | 1 | 1 | 4 | 2 |
| 407 | 2.40 | 4 | 3 | 2 | 2 | 1 |
| 404 | 2.40 | 4 | 8 | 10 | 6 | 7 |
| 405 | 1.48 | 7 | 11 | 11 | 11 | 10 |
| 410 | 1.40 | 8 | 5 | 5 | 1 | 3 |
| 411 | 1.00 | 9 | 2 | 3 | 3 | 5 |
| 403 | -1.45 | 10 | 9 | 6 | 5 | 8 |
| 406 | -1.91 | 11 | 6 | 8 | 7 | 11 |

Culture; each plotted with TCRsc. While data is available to define and examine the effect of Quality, no evidence has been found that Quality affects safety/ergonomics, thus it will not be considered in the box plot analysis. The principle scores in these charts are created from averages of the individual survey question responses corresponding to each principle category. The X axis was made up of facilities and their corresponding TCRsc values arranged from lowest to highest, so that any trend may be revealed visually (Figure 9-Figure 11). Any remaining outliers were removed from these charts, for clarity.

A visual analysis of these box plots reveals several characteristics. The facilities with negative case rate scores all had a large variance in the survey response averages for each principle. For example, facilities 403 and 406, representing the two lowest TCR scores, had responses that spanned nearly the entire range of possible survey answers in the culture category. The implication is that these companies do not have good understanding of their proficiency in these areas, have an uninformed work force, or both. In either case, these are not the

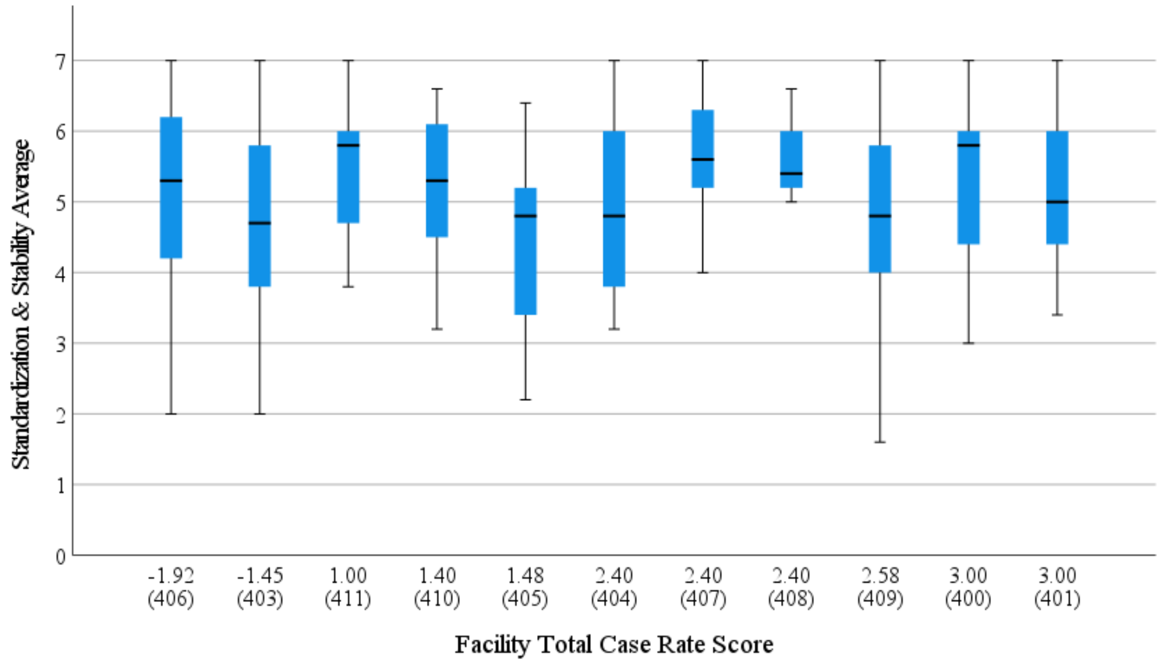



Figure 9: Box Plot of Standardization and Stability Average Score by Facility TCRsc

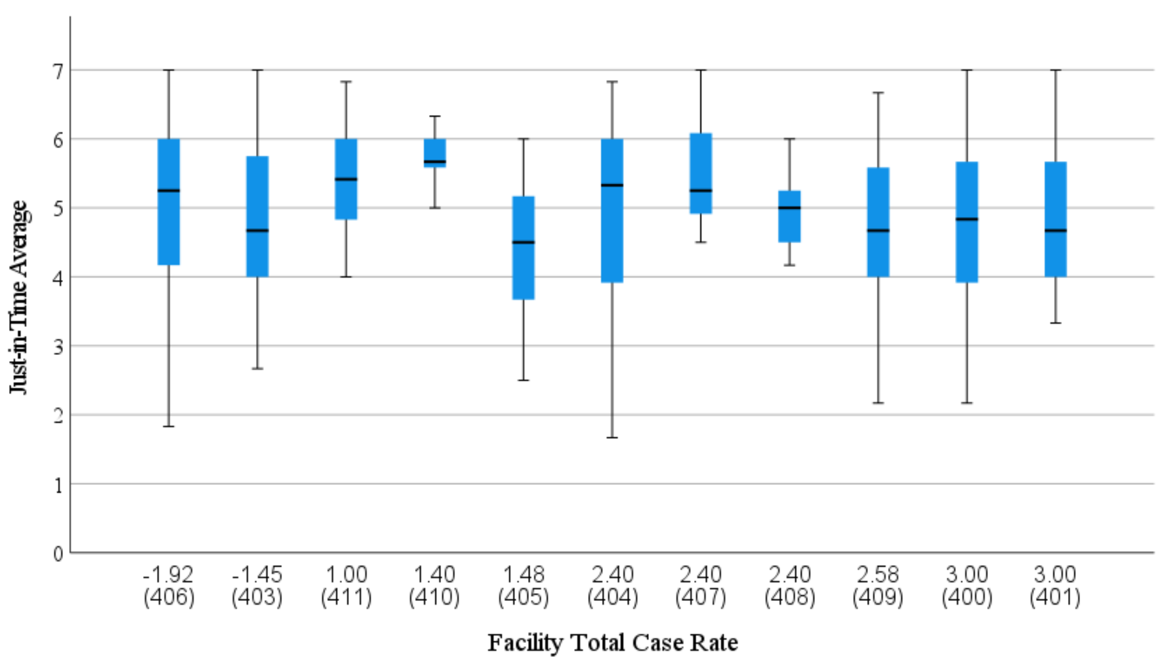



Figure 10: Box Plot of JIT Average Score by Facility TCRsc

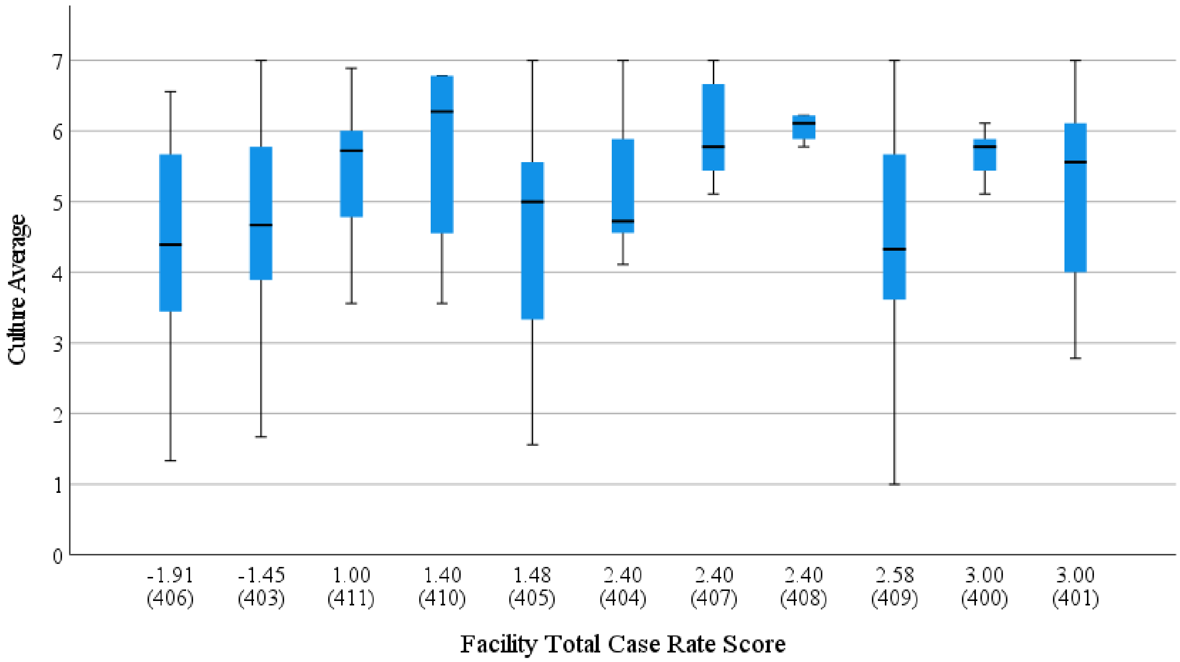



Figure 11: Box Plot of Culture Average Score by Facility TCRsc

characteristics of a well-planned LM implementation or well-operating LM system. While some companies had high variance in survey responses with positive safety scores, all companies with negative safety scores had high variance in survey responses in all categories.

Conversely, facilities 407 and 408, both containing positive case rate scores, had high adoption scores and very little variance in the survey response averages for Culture. This is an indication that these facilities had both high adoption levels for this principle, and the work force was aware of, and part of, this proficiency. Other facilities with high scores and small variance in survey responses had positive case rate scores as well. While the facilities with small survey response variance were not the highest achieving in safety scores, all facilities with small variance had a positive, or better than industry average, score.

### 5.5.4 Scatter Plot Analysis

To further examine the data visually, scatter plots were created using S&S, JIT, and Culture, each graphed with TCRsc (Figure 12-Figure 14). A scatter plot is a well-known basis technique to explore correlations, trends, and clusters in bivariate data [219]. In these scatter plots, each plotted data point represents the LM principle adoption average score from a single survey response (Y-Axis) and the TCRsc for that respondent's facility (X-Axis). Trendlines were also plotted to indicate a trend in the relationship between the principle adoption score (independent variable) and the facility TCRsc (dependent variable). As with the box plots, the independent variables were plotted from lowest to highest average adoption level scores, while the dependent variable was plotted from lowest to highest (worst to best). While no strong relationships were indicated, a marked upward sloping trendline for Culture and TCRsc indicates a positive relationship between Culture adoption and favorable safety incidence rates. Another characteristic from these plots is that the highest number of data points resided in the positive principle adoption level and positive TCRsc quadrant, indicating that the studied facilities were

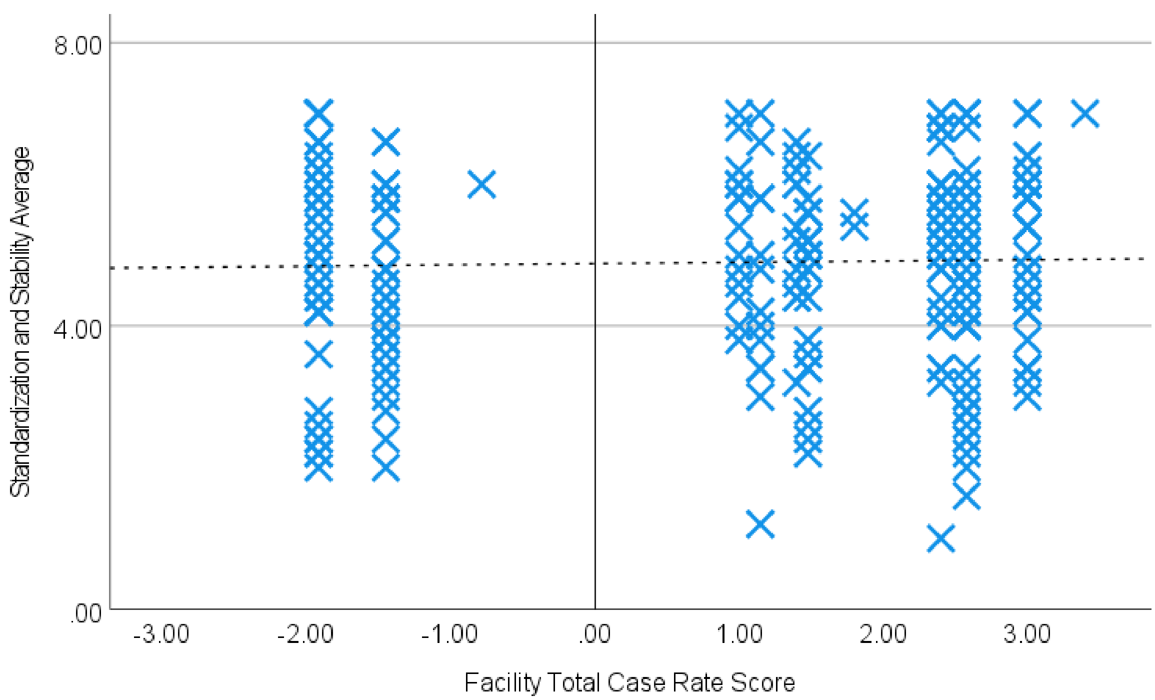



Figure 12: Scatterplot of Standardization/Stability by Facility TCRsc, with Trendline

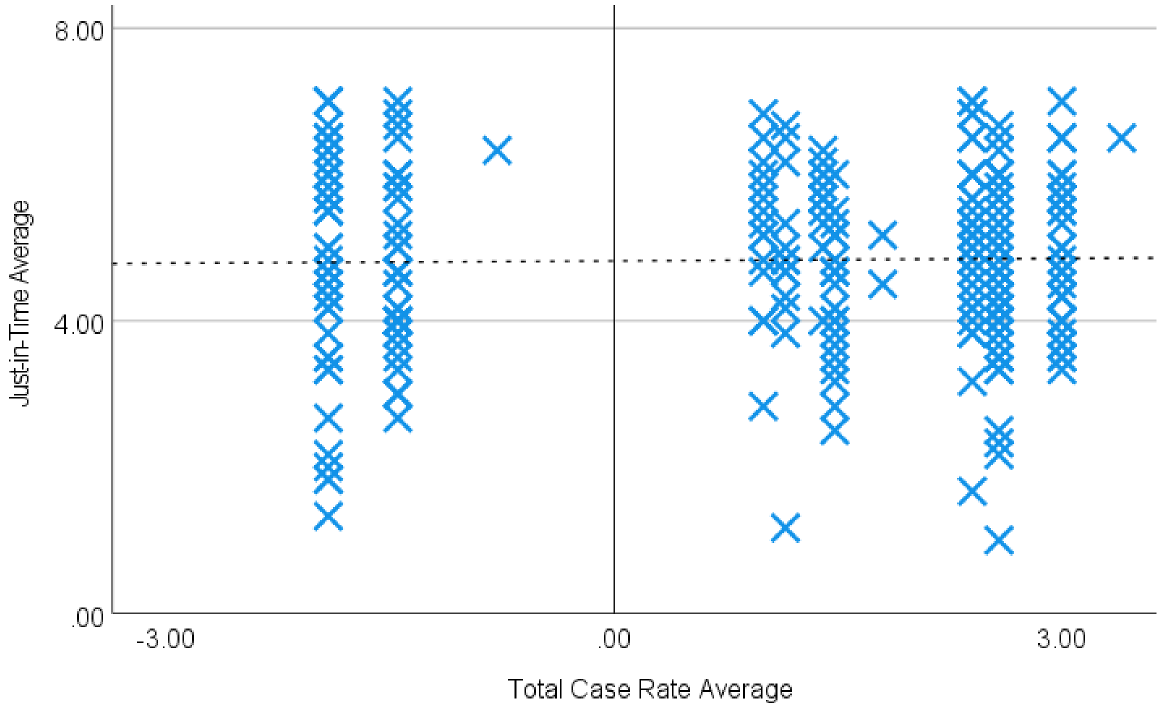



Figure 13: Scatterplot of Just-in-Time by TCRsc, with Trendline

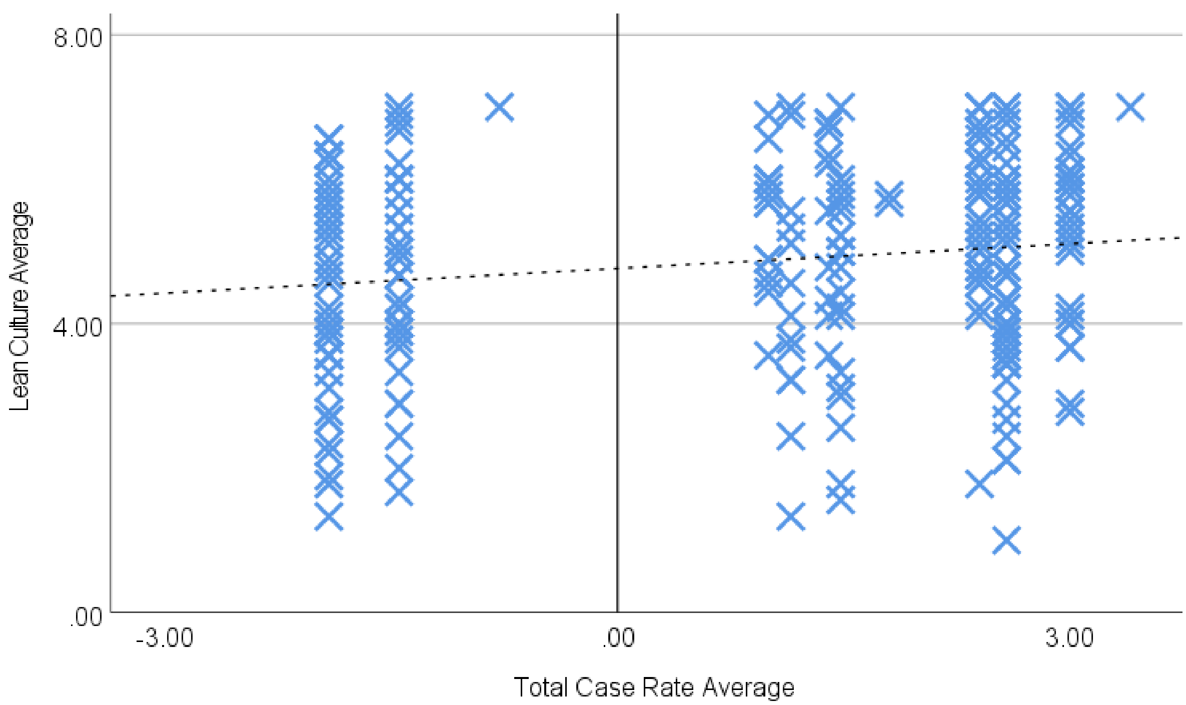



Figure 14: Scatterplot of Lean Culture by TCRsc, with Trendline

above average in both safety incidence rates and LM principle adoption.

The intention of this research was not to try and explain a facility's safety incidence rates solely with their adoption level of lean principles. Many explanatory factors determine the safety incidence rates of a company, such as the quality of their safety programs, the frequency of OSHA voluntary inspections [220], and even how effortlessly a company's business goals are met [221]. The purpose of this study is to determine whether the adoption level of lean principles has any association with safety incidence rates, whatever the strength of that association happens to be. This exploratory analysis resulted in some inferences that effects do exist, particularly pertaining to Culture. A more detailed statistical analysis would be necessary to explain the relationship between LM principles and safety/ergonomics conclusively.

### 5.6 Descriptive Statistics

A Pearson's correlation matrix was created to detect and examine the bivariate relationships found in the data set. The matrix for facility-level data (N=11) can be found in Table 20, while the matrix for individual-level data (N=271) is found in Table 21. For facility-level data, several significant correlations were found within independent variables and within dependent variables, which was expected within LM principles and within incidence rates. However, no correlations

Table 20: Descriptive Statistics and Correlation Matrix for Facility-Level Data (N=11)

| | Mean | S.D. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| 1. TCRsc | 1.481 | 1.694 | -- | | | | | | |
| 2. DARTsc | 1.059 | 1.128 | 0.937** | -- | | | | | |
| 3. DAFWIIsc | 0.663 | 0.435 | 0.660* | 0.785** | -- | | | | |
| 4. S&S | 5.092 | 0.363 | 0.229 | 0.071 | 0.213 | -- | | | |
| 5. Quality | 4.924 | 0.351 | 0.190 | 0.040 | 0.076 | 0.826** | -- | | |
| 6. JIT | 4.977 | 0.366 | 0.033 | -0.150 | -0.149 | 0.787** | 0.781** | -- | |
| 7. Culture | 5.220 | 0.582 | 0.472 | 0.361 | 0.324 | 0.844** | 0.789** | .784** | -- |

$*p < 0.05$, $**p < 0.01$

Table 21: Descriptive Statistics and Correlation Matrix for Individual Data (N=271)

| | Mean | S.D. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| 1. TCRsc | 1.050 | 1.871 | -- | | | | | | |
| 2. DARTsc | 0.683 | 1.191 | 0.936** | -- | | | | | |
| 3. DAFWIIsc | 0.543 | 0.483 | 0.449** | 0.590** | -- | | | | |
| 4. S&S | 4.898 | 1.320 | 0.026 | 0.021 | 0.057 | -- | | | |
| 5. Quality | 4.773 | 1.368 | 0.057 | 0.045 | 0.034 | 0.839** | -- | | |
| 6. JIT | 4.830 | 1.200 | 0.017 | -0.007 | 0.013 | 0.758** | 0.839** | -- | |
| 7. Culture | 4.884 | 1.375 | 0.155* | 0.154* | 0.089 | 0.749** | 0.822** | 0.794** | -- |

*p < 0.05, **p < 0.01

were found between independent and dependent variables. The matrix for individual data, however, indicated a significant correlation between perceived LM Culture adoption and both TCRsc and DARTsc, in agreement with the rank comparison and scatterplot analyses.

While a relationship between Culture adoption and incidence rates has been demonstrated in most analysis methods conducted to this point, any relationship with JIT remains undetermined, and no evidence has been found indicating a relationship between S&S adoption and the incidence rates. Since Pearson's analysis is a bivariate test (i.e., examines only one pair of variables) multivariate relationships cannot be determined. If any determination is to be made concerning JIT and S&S, multivariate methods may be needed to investigate whether JIT and S&S may have explanatory power when tested in combination with other variables.

**5.7 Statistical Analysis**

Two parametric testing methods were used to analyze variable associations, regression analysis and covariance-based SEM. For regression analysis, two forms were used, simple regression and multiple regression. Simple regression analysis is used to calculate the effect of one causal (i.e., independent) variable on one affected (i.e., dependent) variable; while multiple regression is used when calculating the effect of two or more independent variables on a single dependent variable [207]. SEM is a collection of statistical techniques that allow a set of complex relationships between one or more independent variables and one or more dependent variables to be examined [209]. IBM SPSS version 28 and AMOS version 28 software programs were used for regression analysis and SEM, respectively.

### 5.7.1 Data Types and Normality

The Likert scale has been one of the most widely used psychometric rating scales in survey research based on attitude and perception measurement [204, 222, 223]. However, one drawback of Likert survey use is that it can generate ordinal data, and the use of parametric statistical tests on ordinal data is often criticized by the scientific community [222]. While several authors defend the use of ordinal Likert data in parametric statistical testing [193] [224] [225] this study is designed to calculate composite LM principle scores from the survey responses, resulting in interval data that is appropriate for parametric testing such as regression analysis and SEM [193-197].

Both the independent variable defined by Likert-scale responses, and the dependent variable defined by published safety data, follow a non-normal distribution in the collected data. A Shapiro-Wilk test was conducted to test for data normality, and the results of that test can be found in Table 22. A Shapiro-Wilk significance value less than 0.05 indicates a non-normal distribution for that variable (the null hypothesis in a Shapiro-Wilk test is that the data is normally distributed). Several data that were used to define both independent and dependent variables were found to have non-normal distributions. The use of non-normal data in parametric testing is a criticized technique [222], however, both Blanca et al. [226] and Norman [222] support the use of parametric tests on non-normally distributed data.

Table 22: Shapiro-Wilk Normality Test Results for All Variables

| Variable | N | Level of Analysis | Shapiro-Wilk Sig. |
|---|---|---|---|
| S&S | 11 | Facility | 0.788 |
| Quality | 11 | Facility | 0.193 |
| JIT | 11 | Facility | 0.618 |
| Culture | 11 | Facility | 0.326 |
| TCRsc | 11 | Facility | 0.009 |
| DARTsc | 11 | Facility | 0.027 |
| DAFWIIsc | 11 | Facility | 0.699 |
| S&S | 271 | Individual | < 0.001 |
| Quality | 271 | Individual | < 0.001 |
| JIT | 271 | Individual | < 0.001 |
| Culture | 271 | Individual | < 0.001 |
| TCRsc, DARTsc, DAFWIIsc | 271 (15) | Individual | < 0.001 |
| S&S | 289 | Individual—S&S Only | < 0.001 |
| TCRsc, DARTsc, DAFWIIsc | 289 (15) | Individual—S&S Only | < 0.001 |
| JIT | 284 | Individual—JIT Only | < 0.001 |
| TCRsc, DARTsc, DAFWIIsc | 284 (15) | Individual—JIT Only | < 0.001 |
| Culture | 281 | Individual—Culture Only | < 0.001 |
| TCRsc, DARTsc, DAFWIIsc | 281 (15) | Individual—Culture Only | < 0.001 |

Many studies dating back to the 1930s consistently show that parametric statistics are robust with respect to Likert and non-normal data [222]. This research employed regression analysis and SEM, both parametric techniques, to perform hypothesis testing on Likert-scale and non-normal data. The analysis method used in this study is designed to test large sample sizes, thus data normality may be achieved in future studies with larger sample sizes per the central limit theorem [227]. Due to the limited sample size and data non-normality in this study, non-parametric and robust regression techniques are used to corroborate any findings derived from these parametric tests, to alleviate any controversy in the findings.

### 5.7.2 Regression Analysis on Qualifying Facilities

Using simple regression, the effect on TCRsc from each of the independent variables of Quality, JIT, Culture, and S&S were examined at the facility-level (N=11). This method replicates that of Camuffo et al. (2015) to a certain degree, where survey data defined independent LM variables, accident rates made up the dependent variables, and the study sample was made up of facilities [176]. The Quality variable reentered consideration due to the possibility of it acting as a suppressor variable [200, 228] in backward-elimination multiple regression testing. The scores from each lean category were averaged for all responses within the same facility to define these independent variables. This analysis was also run for the dependent variables of DARTsc and DAFWIIsc. No statistically significant effects were found between these independent and dependent variables using the simple regression method (Table 23).

A backward-elimination multiple regression method is a stepwise-type procedure where

Table 23: Simple Regression Analysis Results—Facility Level (N=11)

| DV | IV | $R^2$ | Std. Error | Unstd. Est. | P-Value |
|---|---|---|---|---|---|
| TCRsc | S&S | 0.052 | 1.739 | +1.070 | 0.498 |
| | Quality | 0.036 | 1.754 | +0.915 | 0.577 |
| | JIT | 0.001 | 1.785 | +0.155 | 0.922 |
| | Culture | 0.223 | 1.574 | +1.376 | 0.142 |
| DARTsc | S&S | 0.005 | 1.185 | +0.221 | 0.835 |
| | Quality | 0.002 | 1.188 | +0.130 | 0.906 |
| | JIT | 0.023 | 1.175 | -0.463 | 0.660 |
| | Culture | 0.130 | 1.109 | +0.699 | 0.276 |
| DAFWIIsc | S&S | 0.045 | 0.448 | +0.255 | 0.530 |
| | Quality | 0.006 | 0.457 | +0.094 | 0.825 |
| | JIT | 0.022 | 0.454 | -0.178 | 0.661 |
| | Culture | 0.105 | 0.434 | +0.243 | 0.331 |

independent variables are eliminated from analysis one at a time until a significant model is achieved [229]. Using this procedure, the effect on each safety score from all 4 of the LM scores (Quality, JIT, Culture, and S&S) was measured at the facility-level. Results from this analysis can be found in Table 24, while the corresponding SPSS output can be found in Appendix D. Several associations were found using this method, however, many of these associations were achieved through the use of a suppressor variable, i.e., an independent variable added to the model creating significance for another independent variable, while itself insignificant [230]. Horst (1941) was the first to note that variables with little correlation to the dependent variable, i.e. suppressor variables, can contribute to an increased proportion of explained variance [200, 228]. In his classical example, he describes the way that the selection of World War II pilots could be improved by including not only a variable measuring their technical abilities in the prediction equation but also a variable assessing their verbal ability, even though the latter variable is itself unrelated to the criterion (navigating skills) [200, 228]. Therefore, the significant results in models that also contain suppressor variables can be considered valid, but with the qualification that these suppressor variables are an unremovable part of the explanation of effect from the significant variable(s).

Several statistically significant associations were found using the backward-elimination regression procedure (Table 24). Culture was found to have a positive correlation with TCRsc, when controlling for JIT, and when controlling for both JIT and S&S. However, the ANOVA significance values indicated a poor fit for both of these TCRsc models [231]. Both Culture and JIT had significant effects on both DARTsc when modeled together, both with and without S&S as a suppressor variable. JIT and Culture also had significant effects on DAFWIIsc when modeled as a pair. These models with DARTsc and DAFWIIsc as the dependent variables

Table 24: Backward-Elimination Multi-Regression Analysis Results—Facility Level (N=11)

| Dep. Var. | Model | Adj. $R^2$ | Std. Err. of Est. | ANOVA Sig. | Indep. Var. | Unstd. Est. | Std. Error | P-Value |
|---|---|---|---|---|---|---|---|---|
| TCRsc | 1 | 0.222 | 1.495 | 0.265 | S&S | -1.005 | 2.846 | 0.736 |
| | | | | | Quality | -0.281 | 2.629 | 0.919 |
| | | | | | JIT | -3.611 | 2.358 | 0.177 |
| | | | | | Culture | 3.818 | 1.655 | 0.061 |
| | 2 | 0.332 | 1.385 | 0.130 | S&S | -1.123 | 2.430 | 0.658 |
| | | | | | JIT | -3.687 | 2.085 | 0.120 |
| | | | | | Culture | 3.783 | 1.504 | 0.040 |
| | 3 | 0.397 | 1.316 | 0.054 | JIT | -4.051 | 1.833 | 0.058 |
| | | | | | Culture | 3.372 | 1.152 | 0.019 |
| DARTsc | 1 | 0.420 | 0.859 | 0.125 | S&S | -1.04 | 1.635 | 0.548 |
| | | | | | Quality | -0.268 | 1.511 | 0.865 |
| | | | | | JIT | -3.017 | 1.355 | 0.068 |
| | | | | | Culture | 2.860 | 0.951 | 0.024 |
| | 2 | 0.500 | 0.797 | 0.050 | S&S | -1.153 | 1.398 | 0.437 |
| | | | | | JIT | -3.089 | 1.200 | 0.037 |
| | | | | | Culture | 2.827 | 0.866 | 0.014 |
| | 3 | 0.520 | 0.781 | 0.022 | JIT | -3.463 | 1.088 | 0.013 |
| | | | | | Culture | 2.405 | 0.684 | 0.008 |
| DAFWIIsc | 1 | 0.257 | 0.375 | 0.236 | S&S | 0.427 | 0.714 | 0.571 |
| | | | | | Quality | -0.194 | 0.660 | 0.778 |
| | | | | | JIT | -1.306 | 0.591 | 0.069 |
| | | | | | Culture | 0.754 | 0.415 | 0.119 |
| | 2 | 0.354 | 0.350 | 0.116 | S&S | 0.346 | 0.613 | 0.591 |
| | | | | | JIT | -1.358 | 0.526 | 0.036 |
| | | | | | Culture | 0.730 | 0.38 | 0.096 |
| | 3 | 0.409 | 0.334 | 0.050 | JIT | -1.246 | 0.466 | 0.028 |
| | | | | | Culture | 0.856 | 0.293 | 0.019 |

indicated acceptable model fit per the ANOVA significance values.

In all cases where significance and model fit were achieved, Culture had a positive effect on the dependent variable, and JIT a negative effect. These outcomes mark the first statistical indication of the positive influence of Culture and the negative influence of JIT hinted at in the literature review and/or exploratory analysis. As with the exploratory analysis, no effect of S&S on the dependent variables was found, in contrast to the literature review findings.

Of concern with these analysis results, however, are the large adjusted $R^2$ values and strengths of coefficients, both of which are implausible. The small sample size (N=11) created by grouping the data into facility summaries, instead of examining the survey responses individually, can lead to inflation in both explanatory power and effect size [232-235]. According to Anderson, Kelley, and Maxwell (2017), a low sample size can result in an underpowered study, which in turn can lead to false discovery rates and inflated effect-size estimates [235]. Likewise, Akossou and Palm (2013) found that overestimation bias in $R^2$ increases as sample size decreases [233]. The low sample size present in facility-level analysis should be taken into account when considering the effect coefficients and explanatory power values.

### 5.7.3 Regression Analysis on Individual Survey Responses

Using the sample of individual survey responses, each combination of independent and dependent variable was tested using both simple and multiple regression analysis methods. For each survey response, the TCRsc, DARTsc, and DAFWIIsc values were added in accordance with the facility that each person worked in, establishing the dependent variables for each survey case. Since this method examines individual cases (survey responses) instead of facility values, the minimum sample size per facility was no longer required. Therefore, the data set for individual-level analysis ranged from 281-289 in sample size, as responses with blank entries were kept in the sample when those blanks were not within the principle being examined. This experimental design is similar to that of Conti et al. (2006) where regression analysis was used on a sample population consisting of survey responses with added facility metrics, except in their case the independent variable was based on facility metrics and the response variable is defined by survey responses [72]. What is being measured with the individual level examination is how a worker's perception of LM principle adoption levels in their workplace is associated with the incidence rates in that workplace; whereas facility level analysis measured the association between a facility's LM principle composite score, as defined by employee perception, with its incidence rates.

Unlike facility-level analysis, individual-level simple regression analysis indicated a statistically significant relationship between employee-perceived Culture adoption and both TCRsc and DARTsc. However, the adjusted $R^2$, or the explanatory proportion of the dependent variable from the independent variable, was small at 2.6% and 2.7%, respectively. Neither Quality, JIT, nor S&S indicated a statistically significant effect on any of the 3 dependent variables using this method. The results from the individual-level simple regression analysis can be found in Table 25.

As with facility-level analysis, a backward-eliminating multiple regression method was applied to individual-level data. Since all four independent variables were examined together, the sample size was slightly reduced (N=271) as a blank response in any principle invalidated the response. This method found several statistically significant relationships, and again with only a positive effect from Culture and negative effect from JIT (Table 26). But unlike with facility-level analysis, both Culture and JIT were significant in every test with TCRsc and DARTsc, and

Table 25: Simple Regression Analysis Results—Individual Level

| DV | IV | $R^2$ | N | Unstd. Est. | Std. Err. | P-Value |
|---|---|---|---|---|---|---|
| TCRsc | S&S | 0.001 | 289 | 0.036 | 0.084 | 0.674 |
| | Quality | 0.001 | 282 | 0.034 | 0.082 | 0.678 |
| | JIT | 0.000 | 284 | -0.001 | 0.093 | 0.994 |
| | Culture | 0.030 | 281 | 0.232 | 0.079 | 0.004 |
| DARTsc | S&S | 0.000 | 289 | 0.018 | 0.054 | 0.737 |
| | Quality | 0.000 | 282 | 0.013 | 0.052 | 0.810 |
| | JIT | 0.000 | 284 | -0.021 | 0.059 | 0.716 |
| | Culture | 0.030 | 281 | 0.149 | 0.05 | 0.003 |
| DAFWIIsc | S&S | 0.002 | 289 | 0.014 | 0.022 | 0.511 |
| | Quality | 0.000 | 282 | 0.004 | 0.021 | 0.845 |
| | JIT | 0.000 | 284 | -0.006 | 0.024 | 0.802 |
| | Culture | 0.007 | 281 | 0.028 | 0.021 | 0.173 |

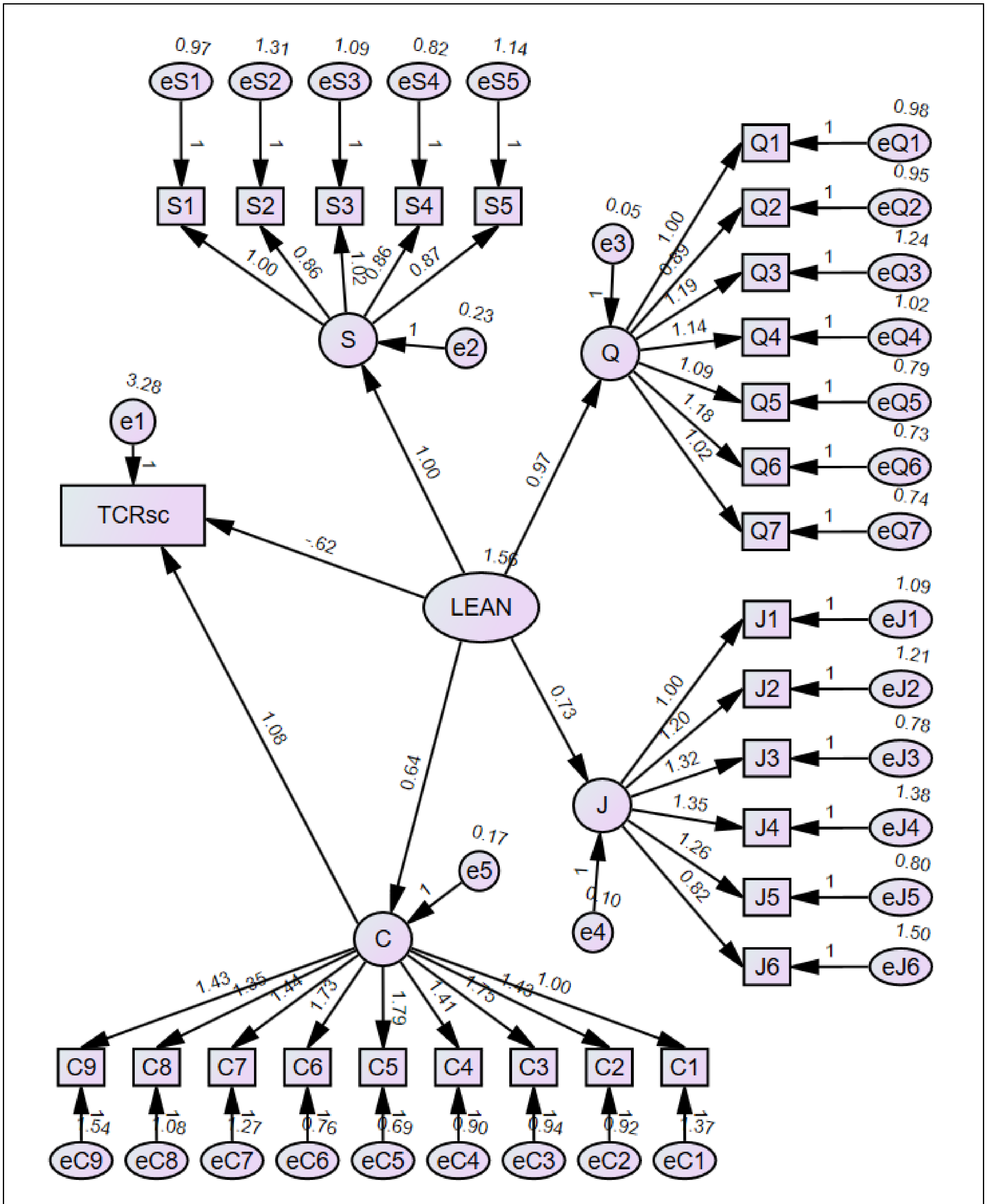
all possessed good model fit. These significant effects were achieved both with and without Quality and S&S as suppressor variables. However, all analysis results with DAFWIIsc as the dependent variable failed to reach model fit with ANOVA significance levels well above the 0.05 threshold. One other considerable difference with individual-level analysis is that the effect sizes and adjusted $R^2$ values were more plausible at 5-6%.

### 5.7.4 Structural Equation Modeling (SEM)

The SEM method of analysis replicates the design intent of the Huang, Harris, and Loyd [181] survey instrument concerning the determination of both lean and its individual principles. The SEM construction designed to test the relationship between this Lean construct and TCRsc, DARTsc, and DAFWIIsc (Figure 4) failed to produce a good model fit or statistically significant coefficients. However, by connecting the Culture construct as a mediating variable (Figure 15) to the safety score similar to the model introduced by Loyd [191], a statistically significant

Table 26: Backward-Elimination Multi-Regression Analysis Results—Individual Level

| DV | Model | Adj. $R^2$ | Std. Err. of Est. | ANOVA Sig. | IV | Unstd. Est. | Std. Error | P-Value |
|---|---|---|---|---|---|---|---|---|
| TCRsc | 1 | 0.045 | 1.828 | 0.003 | S&S | -0.164 | 0.159 | 0.305 |
| | | | | | Quality | -0.008 | 0.194 | 0.969 |
| | | | | | JIT | -0.361 | 0.182 | 0.049 |
| | | | | | Culture | 0.584 | 0.152 | < 0.001 |
| | 2 | 0.049 | 1.825 | < 0.001 | S&S | -0.167 | 0.139 | 0.231 |
| | | | | | JIT | -0.364 | 0.166 | 0.030 |
| | | | | | Culture | 0.582 | 0.143 | < 0.001 |
| | 3 | 0.047 | 1.826 | < 0.001 | JIT | -0.445 | 0.152 | 0.004 |
| | | | | | Culture | +0.518 | 0.133 | < 0.001 |
| DARTsc | 1 | 0.058 | 1.155 | < 0.001 | S&S | -0.085 | 0.101 | 0.396 |
| | | | | | Quality | -0.013 | 0.123 | 0.918 |
| | | | | | JIT | -0.297 | 0.115 | 0.011 |
| | | | | | Culture | 0.411 | 0.096 | < 0.001 |
| | 2 | 0.062 | 1.153 | < 0.001 | S&S | -0.091 | 0.088 | 0.303 |
| | | | | | JIT | -0.302 | 0.105 | 0.004 |
| | | | | | Culture | 0.407 | 0.09 | < 0.001 |
| | 3 | 0.062 | 1.153 | < 0.001 | JIT | -0.346 | 0.096 | < 0.001 |
| | | | | | Culture | +0.373 | 0.084 | < 0.001 |
| DAFWIIsc | 1 | 0.004 | 0.482 | 0.273 | S&S | 0.028 | 0.042 | 0.503 |
| | | | | | Quality | -0.032 | 0.051 | 0.528 |
| | | | | | JIT | -0.058 | 0.048 | 0.229 |
| | | | | | Culture | 0.078 | 0.04 | 0.054 |
| | 2 | 0.007 | 0.482 | 0.191 | S&S | 0.015 | 0.037 | 0.677 |
| | | | | | JIT | -0.07 | 0.044 | 0.111 |
| | | | | | Culture | 0.069 | 0.038 | 0.068 |
| | 3 | 0.010 | 0.481 | 0.101 | JIT | -0.063 | 0.040 | 0.118 |
| | | | | | Culture | +0.075 | 0.035 | 0.033 |




| $\chi^2$/df | RMSEA | SRMR | NFI | CFI | AGFI | TLI | Lean→TCRsc | Culture→TCRsc |
|---|---|---|---|---|---|---|---|---|
| 2.72 | 0.08 | 0.05 | 0.85 | 0.90 | 0.77 | 0.89 | -0.621 p=0.012 | +1.082 p=0.002 |

Figure 15: Structural Equation Model with Culture as Mediating Variable

association between both Lean and Culture constructs with TCRsc and DARTsc was found, but the model fit indices did not improve with this new arrangement.

Model fit criteria for this study are based on Hu and Bentler's two-index presentation strategy (Table 27) [236, 237]. While the model represented in Figure 15 did not satisfy these criteria, the indices are acceptable by other standards found in the literature [107, 238], therefore the details and results from this analysis method are used in this analysis.

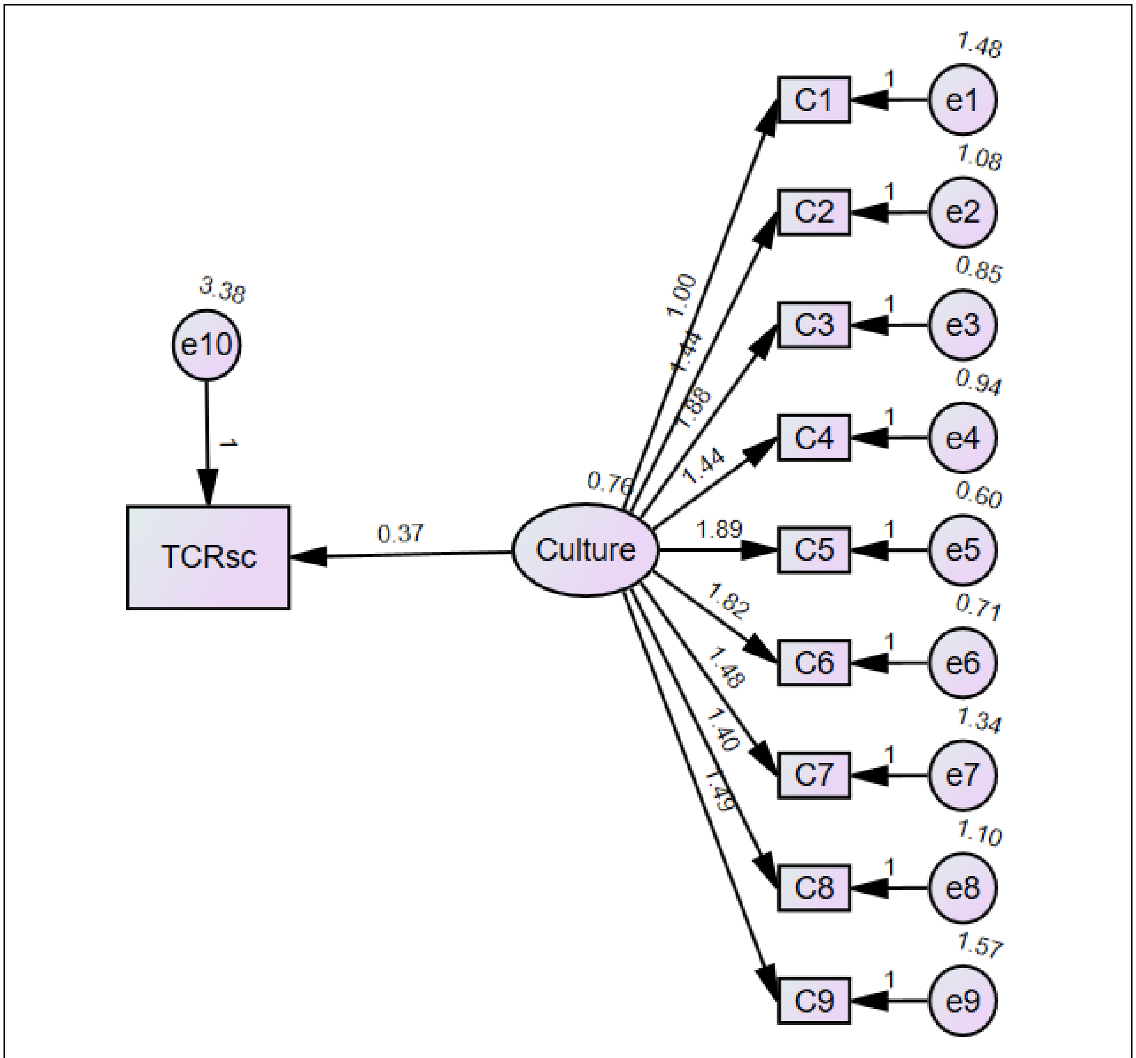
Table 27: Hu and Bentler's Two-Index Presentation Strategy

| **Fit Index Combination** | **Combination Rules** |
|---|---|
| NNFI (TLI) and SRMR | NNFI (TLI) $\geq$ 0.96 and SRMR $\leq$ 0.09 |
| RMSEA and SRMR | RMSEA $\leq$ 0.06 and SRMR $\leq$ 0.09 |
| CFI and SRMR | CFI $\geq$ 0.96 and SRMR $\leq$ 0.09 |

The second SEM analysis method used was to test for relationships between the individual constructs of Lean and the 3 safety scores (Figure 5). From this analysis, only the Culture construct demonstrated statistically significant relationships with two of the dependent variables, TCRsc and DARTsc (Figure 16). More importantly, the SEM analysis of these two constructs demonstrated good model fit with SRMR=0.04 and CFI=0.96, satisfying the Hu and Bentler two-index criteria [236, 237] for acceptable model fit.

### 5.7.5 Non-Parametric Methods and Robust Regression

Several non-parametric analysis methods are compatible with Likert scale and non-normal data [205, 206]. Both Kendall's Tau B and Spearman's Rho are non-parametric bivariate analysis methods for testing the strength and direction of the correlation between two variables. The drawback with these tests is that they are unable to replicate a multiple regression or SEM analysis as they can only examine the relationship between one independent and one dependent




| $\chi^2$/df | RMSEA | SRMR | NFI | CFI | AGFI | TLI | Culture→TCRsc | Culture→DARTsc |
|---|---|---|---|---|---|---|---|---|
| 3.02 | 0.09 | 0.04 | 0.94 | 0.96 | 0.89 | 0.95 | +0.370 p=0.005 | +0.241 p=0.004 |

Figure 16: Structural Equation Model with Culture Only

variable.

Parametric analysis indicated a correlation between both JIT and Culture with both TCRsc and DARTsc through multiple regression and SEM analysis. Both Kendall's Tau B and Spearman's Rho tests confirmed the significance and direction of the correlations with culture as the independent variable. However, the parametric tests that found an association between JIT and the dependent variables were all multiple regression tests, which are unable to be replicated

Table 28: Non-Parametric Testing for JIT and Culture

| I.V. | D.V. | N | Test | Analysis Level | Effect | p-Value |
|---|---|---|---|---|---|---|
| JIT | TCRsc | 284 | Kendall's Tau B | Individual | -0.041 | 0.340 |
| JIT | TCRsc | 284 | Spearman's Rho | Individual | -0.053 | 0.372 |
| JIT | DARTsc | 284 | Kendall's Tau B | Individual | -0.047 | 0.278 |
| JIT | DARTsc | 284 | Spearman's Rho | Individual | -0.063 | 0.292 |
| Culture | TCRsc | 281 | Kendall's Tau B | Individual | +0.099 | 0.02 |
| Culture | TCRsc | 281 | Spearman's Rho | Individual | +0.138 | 0.02 |
| Culture | DARTsc | 281 | Kendall's Tau B | Individual | +0.130 | 0.00 |
| Culture | DARTsc | 281 | Spearman's Rho | Individual | +0.177 | 0.00 |

with these bivariate methods. Therefore, non-parametric methods did not find a statistically significant correlation between JIT and any dependent variable. The results from non-parametric analysis can be found in Table 28.

Robust regression is an analysis method that can be used where non-normality and outliers are present in the data, by removing or modifying outliers in the regression calculation process [239, 240]. As with non-parametric analysis, this method of analysis was used to confirm the findings from regression analysis, both at the facility and the individual level. IBM SPSS Version 28 was used to perform robust regression analysis on the same data sets where traditional multiple regression analysis was used. As with traditional regression, the robust multiple regression analysis found statistically significant effects from JIT and Culture on both TCRsc and DAFWIIsc at the individual level, but not with facility level analysis. The robust regression function in SPSS does not provide the p-values for the effects, therefore these values were calculated with the T. DIST command in Microsoft Excel 365 version 2207. The results of this analysis can be found in Table 29.

Table 29: Robust Multiple Regression Analysis Results

| I.V. | D.V. | Effect | Std. Error | t-Value | df | p-Value |
|---|---|---|---|---|---|---|
| JIT | TCRsc | -0.484 | 0.195 | -2.483 | 268 | 0.013 |
| Culture | | +0.536 | 0.170 | 3.152 | 268 | 0.002 |
| JIT | DARTsc | -0.392 | 0.111 | -3.521 | 268 | < 0.01 |
| Culture | | +0.427 | 0.097 | 4.405 | 268 | < 0.01 |

# Chapter 6 Analysis

Exploratory analysis revealed some evidence that JIT and Culture adoption levels were associated with the dependent variables. Deeper examination using statistical methods revealed several statistically significant results, all of which concerned these two independent variables of JIT and Culture. Additionally, JIT had consistently negative effects on the dependent variables, while Culture had consistently positive effects. The most surprising result is that no evidence, either through exploratory or statistical analyses, was found to support the narrative that 5S adoption had association with incidence rates.

Multiple statistical tests found that Culture adoption had a positive influence on all three dependent variables, while no testing outcome indicated in a negative relationship. Non-parametric analyses of the correlation between Culture and all 3 dependent variables had statistical significance and a small positive effect, and are an important substantiation given the non-normality of the data being examined.

Opposite to Culture, multiple statistical tests found that JIT adoption had a negative influence on all three dependent variables while no analysis method resulted in a positive relationship between JIT adoption and any safety score. These effects were also corroborated through Robust Regression analysis, but unlike with Culture, non-parametric analysis was inconclusive due to the inability to test multiple independent variables together as with multiple regression analysis, which is where the findings on JIT occurred.

While the direction of the effects from JIT and Culture remained consistent, facility-level analysis found higher adjusted $R^2$ and stronger effect magnitude. The differences between facility-level and individual-level analyses can be explained by the difference in sample size, as lower sample sizes result in lower statistical power, which tends yield inflated effect-size estimates [232-235]. While effect size is important and this incongruity is noteworthy, the critical information to this study is statistical significance and direction of effect for the independent-dependent variable relationships. Additionally, the comparison of the effect magnitude from JIT and Culture when analyzed together, or when compared across equivalent tests, allows for determination of the overall effect from the use of both methods.

Finally, Lean as a holistic system was only found to have a statistically significant effect when using SEM with Lean as a construct of the 4 principles and Culture as a mediating variable (Figure 15). While this analysis failed to achieve good model fit, it is noteworthy that both Lean and Culture showed a statistically significant effect on TCRsc. Also noteworthy is the fact that Lean showed a negative effect on TCRsc, while Culture showed a positive effect that was sufficient to overcome the negative effect from Lean.

Ultimately, the result used for hypothesis testing is based on individual-level multiple regression analysis with Culture and JIT as the independent variables and TCRsc as the dependent variable. This method represents the primary intent of the study design, and the results were supported by exploratory analysis, SEM, non-parametric methods, and/or robust regression analyses. The results used for hypothesis testing are displayed in Table 30.

Table 30: Statistical Analysis Results for Hypothesis Testing

| **I.V.** | **D.V.** | **Adj. $R^2$** | **Effect (B)** | **Std. Error** | **Effect (Beta)** | **p-Value** |
|---|---|---|---|---|---|---|
| JIT | TCRsc | 0.05 | -0.445 | 0.152 | -0.285 | 0.004 |
| Culture | | | +0.518 | 0.133 | +0.381 | < 0.001 |
| JIT | DARTsc | 0.06 | -0.346 | 0.096 | -0.349 | < 0.001 |
| Culture | | | +0.373 | 0.084 | +0.430 | < 0.001 |

The adjusted $R^2$ value of 0.05 indicates that the adoption level of LM, specifically in the principles of JIT and Lean Culture, explain 5% of the variance in a facility's OSHA total case rate, and explain 6% of the variance in cases requiring days away, restriction, or transfer. While these explanatory proportions seem low, recall that LM is not specifically designed to impact safety, and even the presence of any effect on S/E is disputed in literature.

These adjusted $R^2$ values would be disappointing metrics if the independent variables were related to an improved safety program such as behavior-based safety. But in the context of LM, or any other factor thought to be unrelated to safety, these explanatory proportions constitute a substantial finding. The effect of -0.445 from JIT suggests an increase of 0.445 incidents per 100 workers per year, for every 1-point increase in employee-perceived adoption level (using the same 7-point Likert scale as used in this study). Likewise, a 1-point increase in adoption level of Lean culture is associated with a decrease of 0.518 incidents per 100 workers per year. This study ultimately suggests that a LM implementation with a Lean Culture adoption level at least equal to the JIT adoption level would result in an enhancement in worker safety. Conversely, JIT implementation with lagging or absent Lean Culture adoption, would result in a marginal detriment to worker safety.

# Chapter 7 Conclusion

Several statistically significant and consistent findings from this study provide some clarity to the research question: what is the effect of LM on S/E? This study found evidence of several relationships between LM principle adoption and safety incidence rates, offering some enlightenment to the disputed nature of this relationship. With agreement between parametric, non-parametric, and robust regression analysis coefficients; these results are suitable for hypothesis testing using the discovered relationships, despite the non-normally distributed data found in the data set.

## 7.1 Hypothesis Testing

The hypotheses for this study stated that implementation of LM either is ($H_0$) or is not ($H_1$) independent of OSHA incidence rates. For the sample examined in this study, the adoption levels of both Culture and JIT were shown to have statistically significant effects on OSHA incidence rates. While the coefficients of determination were not large, LM implementation is not designed specifically to impact safety, so the weak explanatory power is not of concern. Nevertheless, the notable finding from this study is that statistically significant effects from both LM Culture and JIT principle adoption do exist, therefore the null hypothesis ($H_0$) can be rejected, and the alternate hypothesis ($H_1$) accepted.

## 7.2 Additional Conclusions

Aside from Culture, JIT was the only LM principle that demonstrated statistically significant association with incidence rates. In the multiple regression analyses where JIT and Culture were paired together as independent variables, the positive coefficient from Culture was stronger in magnitude than the negative coefficient from JIT. Also, SEM modeling using only the 4 principle constructs found that only Culture adoption had a statistically significant (and favorable) association with incidence rates, and contained an acceptable model fit. Furthermore, robust multiple regression analysis corroborated the results from multiple regression analyses on the association of Culture and JIT adoption. Therefore, the significant and positive coefficient from Culture adoption was sufficient to overcome the negative associations from adoption level of all other LM principles.

The results of this study contradicts the many claims that LM implementation results in a negative S/E effect. However, this study indicates that while LM principle implementation does account for 5% of the explanation for total incidence rates, the magnitude and direction of effect is determined by the balance in adoption levels of JIT and Culture principles. Our results suggest that, if kept in balance, the adoption of these two principles should yield a benefit to safety. An important take-away from this study is the necessity of Culture in an LM implementation as it pertains to a safe work environment.

The results of this study generally support the findings of Camuffo et al. (2015) and Mousavi et al. (2020) who empirically found that LM maturity was positively associated with safety [173, 176]. These results also generally support the experimental finding of Brenner et al. (2004) of a negative relationship between JIT and increased CTD cases [95]. However, this study did not concur with the high levels of explanatory power in studies with similar effect findings.

Several conclusions can be generated from the outcome of this study. Firstly, the fact that statistical significance and good model fit were achieved in many areas of this analysis reinforces the notion that an association between LM and S/E exists within the LM principles of JIT and Culture. Secondly, these same model-fit and statistical significance characteristics reinforce the sense that a larger study using this method is worthy of consideration. Thirdly, given these found safety implications it can be argued that Culture is vital and perhaps the most important principle of Lean, which would be consistent with the Loyd model (Figure 1) having Culture as the central pillar of Lean and TPS [191]. And lastly, it is surprising that no statistically significant effects were found in this research with S&S as the independent variable, which contradicts the literature review findings that 5S, a component of S&S, has an overwhelmingly positive effect on S/E.

### 7.3 Effects of Outlier Removal on Statistical Test Results

According to Walfish (2006), it is prudent to report conclusions with and without suspected outliers in the data analysis [241]. Therefore, the same backward-elimination multiple regression analysis used for hypothesis testing was conducted with outliers included in the data set. When including the outlier data, the analysis failed to produce a statistically significant model fit, meaning that no correlations could be gleaned from the data output [206]. These results reinforce the reasoning for the decision to remove these data points. The SPSS output for this analysis can be found in Appendix F.

### 7.4 Assumptions and Limitations

Several assumptions were made in this study:

- The survey respondents answered their job role and quantifiable metrics honestly and accurately [204].
- The published facility incidence data provided by OSHA accurately represented the number of actual incidents incurred at each facility.

The limitations to this study are important in understanding the constraints of the conclusions. These limitations are:

- Fewer than 15 manufacturing facilities and less than 300 survey responses used in this study represents a small sample size with regard to over 640,000 factories and 15.7 million manufacturing employees in the U.S.
- The presence or aptitude of each facility's safety program was not observed. The quality of the safety program could have a confounding effect on the data analysis used in this study.
- The safety metrics used to determine the dependent variables were based on 2020 facility and industry standard incidence rates, while the survey was conducted in the first half of 2022. Facility incidence rates for 2021 were already available at the time of these analyses, however the BLS industry standard rates used to normalize the safety scores would not be available until November 9, 2022.
- The Covid-19 Pandemic began in the U.S. in 2020, the same year that the incidence rates represent that defined the dependent variables. What effect, if any, that the pandemic had on 2020 incidence rates is unknown.
- Every facility represented in this study was either owned by or a supplier to one corporation. The inclusion of other companies could influence outcomes.
- Non-normal data were used in parametric statistical tests in this study; however, the results were corroborated with non-parametric methods.
- For Likert data, the responses in each category were averaged to calculate the independent variables for that survey. For example, the responses from S1-S5 would be averaged to calculate the S&S score for that survey response.

- A facility's measured adoption levels of the four lean principles do not necessarily indicate that these facilities were implementing or operating a LM system, only principles that are associated with LM.

## 7.5 Recommendations for Future Research

### 7.5.1 Directions Identified from the Literature Review

Krafcik [31] 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 S/E. Brown and O'Rourke [129] established that obstacles to effective worker participation in China must be overcome to realize safety under LM, whereas Kumar and Kumar [168] found that Indian culture embraces the idea that worker participation is a necessary component of LM. The literature review in this study harmonizes with this view, as all outcomes in this review that took place in China and France resulted in 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 S/E outcomes, would be a meaningful contribution to the LM and Safety/Ergonomic communities.

There are signs that unionized companies experience disproportionately negative S/E outcomes [242]. 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 S/E 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 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 [179], in that negative S/E 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 unspecific LM systems or methods 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 S/E 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 S/E. 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 [243, 244], 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.

### 7.5.2 Possible Other Uses for this Experimental Method

While this method is designed for cross-sectional examination of lean and safety data across multiple facilities, this method and resulting data can be used by an individual facility to longitudinally study how the progress of a lean implementation or performance of a lean system is affecting safety over time. While OSHA historic data for individual facilities is publicly available, each facility maintains its own incidence rates and they are available through OSHA mandatory reporting logs. Since data normalization would not be necessary, surveying and querying of internal safety data could take place as frequently as desired, providing as many independent and dependent variable data points as needed.

NIOSH has been concerned about the effect of lean manufacturing on occupational safety since the early period of U.S. adoption [52]. With their resources, influence, and experience with data collection through surveying [245], this proposed method could be used by NIOSH to examine the relationship between lean manufacturing and safety/ergonomics on a nationwide scale.

Several other opportunities are:

- Company or facility-specific analysis and monitoring on the state of LM, and its effects on S/E, within each company/facility.
- Conduct this analysis with more recent S/E data as it becomes available to overcome the time-gap limitation present in this study.

- Expand the survey to collect employees' demographic data such as age and gender to test their effects as additional independent variables, and/or suppressor variables that help explain the LM principle effects on S/E.
- The data gathering and analysis method can be used within a company for continuous improvement monitoring in the areas of LM and safety.
- Adding an independent variable for each facility's safety program aptitude would eliminate a possible confounding effect to the examined relationship between Lean and safety.
- Replacing incidence rates with the number of workers' compensation cases for the dependent variable might prove to be a useful variant to this study, especially as it pertains to more serious injuries and illnesses.
- While this method is designed for cross-sectional analysis, longitudinal analysis could also be conducted by gathering data over time.  However, the release of BLS industry data is almost a year behind all other data, which would only make possible a lagging indication of effect.

## Chapter 8 Bibliography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## Appendix A: References for Each LM Method and Outcome Association

References with citations and symbols for negative (-), positive (+), and neutral/offsetting (+/-) safety/ergonomic outcomes

| | JIT, Work Pacing, Slack Reduction, Chaku-Chaku | Kanban | 5S | Stand-ardized Work | TPM | Kaizen, Problem Solving, Continuous Improvement | Lean Work Cell & Lean Factory Layout | TQM | HPWP | HIM | Unspecified Lean Methods or Systems |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hazard Exposure | | | (-) [60]<br>(+) [24, 61, 66, 67, 76, 77] | | (+) [77, 94] | (-) [60]<br>(+) [67, 77] | (-) [129] | (+) [94] | | | (-) [143, 150]<br>(+) [163] |
| Human Factors, Ergonomics, CTD, MSD, WMSD | (-) [47, 72, 95, 96]<br>(+) [94] | | (+) [24, 60, 66, 67] | | | (-) [47]<br>(+) [60, 67] | (-) [125]<br>(+) [123, 126-128] | | | | (-) [141, 142]<br>(+/-) [143]<br>(+) [144, 145] |
| Overall Safety, General Health & Well-Being | (-) [98, 103]<br>(+/-) [104, 110]<br>(+) [94] | | (+) [83] | (+/-) [104] | | | (+/-) [130]<br>(+) [126-128] | | | (+) [134] | (-) [150, 156, 169]<br>(+/-) [170]<br>(+) [144, 146, 151, 171] |
| Physical Strain | (+/-) [97] | | | | | (+) [68] | | (-) [120] | | | (-) [143, 146, 147] |
| Psychological Psychosocial Well-Being | (-) [101]<br>(+/-) [106] | | | | | | | | | | (-) [156]<br>(+/-) [157] |
| Safety and Health Perception, Safety Climate | (+) [109] | | (+) [78-82] | | | (+) [68, 71] | | (+) [121] | (+) [133, 135] | | (-) [164, 165]<br>(+) [166] |
| Safety Behavior and Safety Participation | | | | | | | | | | | (+/-) [167]<br>(+) [168] |
| Safety Records, Accident Rate, and Safety Performance | (-) [45, 47, 89, 111] | | (+) [66, 84-88] | | | (-) [45, 47]<br>(+) [88] | | (-) [120]<br>(+) [121] | (+) [133] | (+) [134] | (-) [160]<br>(+/-) [167, 172, 173]<br>(+) [174-177] |
| Stress and Mental Strain | (-) [72, 91, 94, 98-103]<br>(+/-) [97, 104, 105] | (-) [70] | (-) [61]<br>(+) [69] | (+/-) [68, 104, 131] | (-) [70]<br>(+) [94] | (-) [70, 71]<br>(+) [72] | (-) [129]<br>(+/-) [130] | (-) [120] | | | (-) [46, 147-153]<br>(+/-) [154, 155] |
| Workload, Work Intensity, and Exhaustive Work | (-) [91, 100, 107]<br>(+/-) [13, 75, 108, 109] | (-) [70] | (+) [69] | | (-) [70] | (-) [70, 73, 74]<br>(+/-) [75] | | | | | (-) [147-152, 158-162] |

## Appendix B: Institutional Review Board Approval for Modified Method

Revised 11/18/2021

## AUBURN UNIVERSITY HUMAN RESEARCH PROTECTION PROGRAM (HRPP)

# REQUEST for MODIFICATION

For Information or help completing this form, contact: The Office of Research Compliance (ORC)
Phone: 334-844-5966 E-Mail: IRBAdmin@auburn.edu

- Federal regulations require IRB approval before implementing proposed changes.
- Change means any change, in content or form, to the protocol, consent form, or any supportive materials (such as the investigator's Brochure, questionnaires, surveys, advertisements, etc.). See Item 4 for more examples.

| | |
|---|---|
| 1. Today's Date | 2/10/2022 |

| 2. Principal Investigator (PI) Name: Click or tap here to enter text. | | | |
|---|---|---|---|
| PI's Title: | Joel Brawner, PhD Candidate | Faculty PI (if PI is a student): | Gregory Harris |
| Department: | Industrial and Systems Engineering | Department: | Industrial and Systems Engineering |
| Phone: | 615-633-7727 | Phone: | 334-844-1407 |
| AU-E-Mail: | Jgb0018@auburn.edu | AU E-Mail: | Gah0015@auburn.edu |
| Contact person who should receive copies of IRB correspondence (Optional): | Click or tap here to enter text. | Department Head Name: | John Evans |
| Phone: | Click or tap here to enter text. | Phone: | 334-844-1418 |
| AU E-Mail: | Click or tap here to enter text. | AU E-Mail: | evansjl@auburn.edu |

| 3. AU IRB Protocol Identification | | |
|---|---|---|
| | 3.a. Protocol Number: 21-333, Brawner | |
| | 3.b. Protocol Title: The Effects of Lean Manufacturing on Occupational Safety and Ergonomics | |
| | 3. c. Current Status of Protocol – For active studies, check ONE box at left; provide numbers and dates where applicable | |
| ☐ | Study has not yet begun; no data has been entered or collected | |
| ☒<br>☐ | In progress If YES, number of data/participants entered: 18 companies have participated, none with adequate sample size for our study.<br>Is this modification request being made in conjunction with/as a result of protocol renewal? ☐ YES ☒ NO | Current Approval Dates<br>From: Click or tap to enter a date. |
| ☐ | Adverse events since last review If YES, describe: Click or tap here to enter text. | To: Click or tap to enter a date. |
| ☐ | Data analysis only | |
| ☐ | Funding Agency and Grant Number: Click or tap here to enter text. | AU Funding Information: Click or tap here to enter text. |
| ☐ | List any other institutions and/ or AU approved studies associated with this project: Click or tap here to enter text. | |

The Auburn University Institutional Review Board has approved this Document for use from
02/11/2022 to --------------
Protocol # 21-333 EP 2108

| 4. Types of Change<br>Mark all that apply, and describe the changes in item 5 | |
|---|---|
| ☐ | **Change in Key Personnel**<br>Attach CITI forms to add new personnel. |
| ☐ | **Additional Sites or Change in Sites, including AU classrooms, etc.**<br>Attach permission forms for new sites. |
| ☐ | **Change in methods for data storage/ protection or location of data/ consent documents** |
| ☐ | **Change in project purpose or project questions** |
| ☒ | **Change in population or recruitment**<br>Attach new or revised recruitment materials as needed; both highlighted version & clean copy for IRB approval stamp |
| ☐ | **Change in study procedure(s)**<br>Attach new or revised consent documents as needed; both highlighted revised copy & clean copy for IRB approval stamp |
| ☐ | **Change in data collection instruments/forms (surveys, data collection forms)**<br>Attach new forms as needed; both highlighted version & clean copy for IRB approval stamp |
| ☐ | **Other**<br>(BUAs, DUAs, etc.) Indicate the type of change in the space below, and provide details in the Item 5.c. or 5.d. as applicable. Include a copy of all affected documents, with revisions highlighted as applicable.<br>Click or tap here to enter text. |

| 5. Description and Rationale |
|---|
| **5.a. For each item marked in Question #4 describe the requested change(s) to your research protocol, and the rationale for each.** |
| The original recruitment population was limited to only supplier companies of the PI's employer, Holley Performance Products, Inc. This expanded population will be recruited through the PIs personal and professional contacts, and may include companies owned by, or affiliated with, the PIs employer. The reason for expanding the recruitment is to increase responses and to gain a broader representation in the survey population. |
| **5.b. Briefly list (numbered or bulleted) the activities that have occurred up to this point, particularly those that involved participants.** |
| The survey has been distributed and some responses have been received. |
| **5.c. Does the requested change affect participants, such as procedures, risks, costs, benefits, etc.** |
| No. |
| **5.d. Attach a copy of all "IRB stamped" documents currently used. (Information letters, consent forms, flyers, etc.)** |
| Previous stamped document is attached. |
| **5.e. Attach a copy of all revised documents (high-lighted revised version and clean revised version for the IRB approval stamp).** |
| Application including both clean and highlighted versions is attached. |

| 6. Signatures |
| --- |
| **Principal Investigator:** Joel D. B[signature] |
| **Faculty Advisor PI, if applicable:** Gregory A. Harris [signature] |

Version Date: 2/7/2022

Re: Protocol #21-333, Brawner

Notes for version "February 7, 2022"

1. Changed date to "Feb. 7, 2022" throughout the document.
2. Item 8b: Added the sentence: "Additional companies may be recruited from the population of American manufacturing companies, if needed."
3. Item 12a: Added the sentence: "American manufacturing companies outside of the Holley supply chain may also be contacted and recruited, as needed."
4. Item 12b: Added the sentence: "American manufacturing companies outside of this scope may also be recruited, as needed."
5. Item 13b: Added the sentence: "Additionally, the survey may be emailed to companies outside of the Holley supply chain, as needed."

AUBURN UNIVERSITY INSTITUTIONAL REVIEW BOARD for RESEARCH INVOLVING HUMAN SUBJECTS

# RESEARCH PROTOCOL REVIEW FORM

## FULL BOARD or EXPEDITED

For Information or help contact **THE OFFICE OF RESEARCH COMPLIANCE (ORC)**

**Phone:** 334-844-5966 **e-mail:** IRBAdmin@auburn.edu **Web Address:** http://www.auburn.edu/research/vpr/ohs/index.htm

Revised 04.01.2021

**Submit completed form to IRBsubmit@auburn.edu**

*Complete this form using Adobe Acrobat Writer (versions 5.0 and greater). Hand written copies not accepted.*

**1. PROPOSED START DATE of STUDY:** August 30, 2021 **Today's Date:** Feb. 7, 2022

**PROPOSED REVIEW CATEGORY (Check one):** ■ FULL BOARD ☐ EXPEDITED

**SUBMISSION STATUS (Check one):** ■ NEW ☐ REVISIONS (to address IRB Review Comments)

**2. PROJECT TITLE:** The Effects of Lean Manufacturing on Occupational Safety and Ergonomics

**3.**

| Joel Brawner | Graduate Student | Industrial and Systems Engineering | jgb0018@auburn.edu |
|---|---|---|---|
| **PRINCIPAL INVESTIGATOR** | **TITLE** | **DEPT** | **AU E-MAIL** |
| 96 Martin Lane, Lafayette, TN 37083 | | 615-633-7727 | jbrawner@nctc.com |
| **MAILING ADDRESS** | | **PHONE** | **ALTERNATE E-MAIL** |

**4. FUNDING SUPPORT:** ■ N/A ☐ Internal ☐ External Agency: ________________ ☐ Pending ☐ Received

**For federal funding, list agency and grant number (if available).** ________________

**5a. List any contractors, sub-contractors, other entities associated with this project:**

________________

**b. List any other IRBs associated with this project (including Reviewed, Deferred, Determination, etc.):**

________________

## PROTOCOL PACKET CHECKLIST

**All protocols must include the following items:**

- ■ **Research Protocol Review Form** (All signatures included and all sections completed)
  (Examples of appended documents are found on the OHSR website: http://www.auburn.edu/research/vpr/ohs/sample.htm)
- ■ **CITI Training Certificates** for all Key Personnel.
- ■ **Consent Form or Information Letter** and any Releases (audio, video or photo) that the participant will sign.
- ■ **Appendix A**, "Reference List"
- ■ **Appendix B** if e-mails, flyers, advertisements, generalized announcements or scripts, etc., are used to recruit participants.
- ■ **Appendix C** if data collection sheets, surveys, tests, other recording instruments, interview scripts, etc. will be used for data collection. Be sure to attach them in the order in which they are listed in # 13c.
- ☐ **Appendix D** if you will be using a debriefing form or include emergency plans/procedures and medical referral lists (A referral list may be attached to the consent document).
- ■ **Appendix E** if research is being conducted at sites other than Auburn University or in cooperation with other entities. A **permission letter** from the site / program director must be included indicating their cooperation or involvement in the project. NOTE: If the proposed research is a multi-site project, involving investigators or participants at other academic institutions, hospitals or private research organizations, a letter of **IRB approval** from each entity is required prior to initiating the project.
- ☐ **Appendix F** - Written evidence of acceptance by the host country if research is conducted outside the United States.

6. **GENERAL RESEARCH PROJECT CHARACTERISTICS**

## 6A. Research Methodology

**Please check all descriptors that best apply to the research methodology.**

**Data Source(s):** ☒ New Data ☐ Existing Data

**Will recorded data directly or indirectly identify participants?**
☐ Yes ☒ No

**Data collection will involve the use of:**

- ☐ Educational Tests (cognitive diagnostic, aptitude, etc.)
- ☐ Interview
- ☐ Observation
- ☐ Location or Tracking Measures
- ☐ Physical / Physiological Measures or Specimens (see Section 6E.)
- ☑ Surveys / Questionnaires
- ☑ Internet / Electronic
- ☐ Audio
- ☐ Video
- ☐ Photos
- ☐ Digital images
- ☐ Private records or files
- ☐ Other: ______________________________

## 6B. Participant Information

**Please check all descriptors that apply to the target population.**
☒ Males ☒ Females ☐ AU students

**Vulnerable Populations**
☐ Pregnant Women/Fetuses ☐ Prisoners ☐ Institutionalized
☐ Children and/or Adolescents (under age 18 in AL)

**Persons with:**
☐ Economic Disadvantages ☐ Physical Disabilities
☐ Educational Disadvantages ☐ Intellectual Disabilities

**Do you plan to compensate your participants?** ☐ Yes ☒ No

## 6C. Risks to Participants

**Please identify all risks that participants might encounter in this research.**

- ☐ Breach of Confidentiality*
- ☐ Deception
- ☒ Psychological
- ☐ None
- ☐ Other:
- ☐ Coercion
- ☐ Physical
- ☐ Social

*Note that if the investigator is using or accessing confidential or identifiable data, breach of confidentiality is always a risk.

## 6D. Corresponding Approval/Oversight

- Do you need IBC Approval for this study?
  ☐ Yes ☑ No

  If yes, BUA # ____________________ Expiration date ____________________

- Do you need IACUC Approval for this study?
  ☐ Yes ☑ No

  If yes, PRN # ____________________ Expiration date ____________________

- Does this study involve the Auburn University MRI Center?
  ☐ Yes ☑ No

  Which MRI(s) will be used for this project? (Check all that apply)
  ☐ 3T ☐ 7T

  Does any portion of this project require review by the MRI Safety Advisory Council?
  ☐ Yes ☑ No

  Signature of MRI Center Representative: ______________________________
  *Required for all projects involving the AU MRI Center*

  Appropriate MRI Center Representatives:
  Dr. Thomas S. Denney, Director AU MRI Center
  Dr. Ron Beyers, MR Safety Officer

7. PROJECT ASSURANCES

## A. PRINCIPAL INVESTIGATOR'S ASSSURANCES

1. I certify that all information provided in this application is complete and correct.
2. I understand that, as Principal Investigator, I have ultimate responsibility for the conduct of this study, the ethical performance this project, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by the Auburn University IRB.
3. I certify that all individuals involved with the conduct of this project are qualified to carry out their specified roles and responsibilities and are in compliance with Auburn University policies regarding the collection and analysis of the research data.
4. I agree to comply with all Auburn policies and procedures, as well as with all applicable federal, state, and local laws regarding the protection of human subjects, including, but not limited to the following:
    a. Conducting the project by qualified personnel according to the approved protocol
    b. Implementing no changes in the approved protocol or consent form without prior approval from the Office of Research Compliance
    c. Obtaining the legally effective informed consent from each participant or their legally responsible representative prior to their participation in this project using only the currently approved, stamped consent form
    d. Promptly reporting significant adverse events and/or effects to the Office of Research Compliance in writing within 5 working days of the occurrence.
5. If I will be unavailable to direct this research personally, I will arrange for a co-investigator to assume direct responsibility in my absence. This person has been named as co-investigator in this application, or I will advise ORC, by letter, in advance of such arrangements.
6. I agree to conduct this study only during the period approved by the Auburn University IRB.
7. I will prepare and submit a renewal request and supply all supporting documents to the Office of Research Compliance before the approval period has expired if it is necessary to continue the research project beyond the time period approved by the Auburn University IRB.
8. I will prepare and submit a final report upon completion of this research project.

My signature indicates that I have read, understand and agree to conduct this research project in accordance with the assurances listed above.

| Joel Brawner | Joel Brawner Digitally signed by Joel Brawner Date: 2022.02.08 20:22:27 -06'00' | Feb. 7, 2022 |
|---|---|---|
| **Printed name of Principal Investigator** | **Principal Investigator's Signature** | **Date** |

## B. FACULTY ADVISOR/SPONSOR'S ASSURANCES

1. I have read the protocol submitted for this project for content, clarity, and methodology.
2. By my signature as faculty advisor/sponsor on this research application, I certify that the student or guest investigator is knowledgeable about the regulations and policies governing research with human subjects and has sufficient training and experience to conduct this particular study in accord with the approved protocol.
3. I agree to meet with the investigator on a regular basis to monitor study progress. Should problems arise during the course of the study, I agree to be available, personally, to supervise the investigator in solving them.
4. I assure that the investigator will promptly report significant incidents and/or adverse events and/or effects to the ORC in writing within 5 working days of the occurrence.
5. If I will be unavailable, I will arrange for an alternate faculty sponsor to assume responsibility during my absence, and I will advise the ORC by letter of such arrangements. <u>If the investigator is unable to fulfill requirements for submission of renewals, modifications or the final report, I will assume that responsibility.</u>

| Gregory A. Harris | Gregory A. Harris, Ph.D., P.E. Digitally signed by Gregory A. Harris, Ph.D., P.E. Date: 2022.02.07 09:54:48 -06'00' | Feb. 7, 2022 |
|---|---|---|
| **Printed name of Faculty Advisor / Sponsor** | **Faculty Advisor's Signature** | **Date** |

## C. DEPARTMENT HEAD'S ASSSURANCE

By my signature as department head, I certify that I will cooperate with the administration in the application and enforcement of all Auburn University policies and procedures, as well as all applicable federal, state, and local laws regarding the protection and ethical treatment of human participants by researchers in my department.

| John L. Evans | [signature] | 2/7/22 |
|---|---|---|
| **Printed name of Department Head** | **Department Head's Signature** | **Date** |

Version Date (date document created): Feb. 7, 2022

8. **PROJECT OVERVIEW: Prepare an abstract that includes:**
(**350** word maximum, in language understandable to someone who is not familiar with your area of study):

a) **A summary of relevant research findings leading to this research proposal:**
*(Cite sources; include a "Reference List" as* ***Appendix A.****)*

b) **A brief description of the methodology, including design, population, and variables of interest**

The effects of lean manufacturing (LM) on occupational safety and ergonomics (OSE) has been a debated topic since the adoption of LM in American manufacturing. The literature contains contradicting accounts of this relationship. However, by conducting a literature review that considered how individual LM methods affected specific OSE outcomes, we found more consistency. For example, use of the just-in-time (JIT) method resulted in 21 negative, 11 neutral, and only 3 positive OSE outcomes in the literature. Meanwhile, use of the 5S method resulted in 23 positive and only 2 negative outcomes. Another key finding from the literature review was the lack of deterministic evidence concerning each company's implementation level of these methods. Therefore, our aim will be to examine the relationship between the implementation level of key LM methods and OSE outcomes.

To determine a company's implementation levels of key LM methods, we will use the employee perception survey authored by Huang, Harris, and Loyd [1]. This validated instrument measures a company's implementation levels in the areas of standardization, built-in-quality, JIT, and lean culture. This survey will be delivered electronically through Qualtrics. Participants will be recruited from a population of supplier manufacturing companies to Holley Performance Products, Inc., the principal investigator's employer. Additional companies may be recruited from the population of American manufacturing companies, if needed. The participation target is 700 current employees.

The survey data will be used to establish a lean "score" for individual companies in the areas of standardization and stability, JIT, and lean culture (data in the category of 'built-in-quality' will not be used in this study). The scores in these LM categories will establish three independent variables to be used in our analysis. The dependent variables will be defined using company-specific incidence rates that are publicly available through the Occupational Safety and Health Administration (OSHA). These incidence rates consist of total case rate (TCR), days away from work due to injury or illness (DAFWII), and days away, restricted, or transferred (DART). A company's TCR, DAFWII, and DART 'scores' will be calculated by subtracting their incidence rates from standard incidence rates in their particular industry. A company's assigned industry will be determined by their classification in the North American Industry Classification System (NAICS). Regression analysis will be used to examine associations between the LM category scores and the incidence rate scores.

9. **PURPOSE.**

a. **Clearly state the purpose of this project and all research questions, or aims.**

This research aims to evaluate the association between individual lean method implementation level and the OSHA outcome metrics of total case rate (TCR), days away, restricted, or transferred (DART), and days away from work due to injury or illness (DAFWII); to better understand the relationship between LM and OSE.

b. **How will the results of this project be used? (e.g., Presentation? Publication? Thesis? Dissertation?)**

Results of this study will be used to further understand how LM effects OSE. Outputs will also serve as a component of the researcher's doctoral dissertation, and publication in a professional journal.

10. **KEY PERSONNEL**. Describe responsibilities. Include information on research training or certifications related to this project. **CITI is required. Be as specific as possible.** (Include additional personnel in an attachment.) *All key personnel must attach CITI certificates of completion.*

**Principal Investigator** Joel Brawner **Title:** Graduate Student **E-mail address** jgb0018@auburn.edu

**Dept / Affiliation:** Auburn University, Industrial and Systems Engineering Department

***Roles / Responsibilities:***

PI, Experimental Design, Statistical Analysis, Data Collection and Interpretation, Report, Participants Recruitment and Consent.

**Individual:** Gregory Harris **Title:** Associate Professor **E-mail address** greg.harris@auburn.edu

**Dept / Affiliation:** Auburn University, Industrial and Systems Engineering Department

***Roles / Responsibilities:***

Faculty Advisor - Oversight of All Study Personnel, Experimental Design, Statistical Analysis, Data Collection and Interpretation, and Report.

**Individual:** ____ **Title:** ____ **E-mail address** ____

**Dept / Affiliation:** ____

***Roles / Responsibilities:***

**Individual:** ____ **Title:** ____ **E-mail address** ____

**Dept / Affiliation:** ____

***Roles / Responsibilities:***

**Individual:** ____ **Title:** ____ **E-mail address** ____

**Dept / Affiliation:** ____

***Roles / Responsibilities:***

**Individual:** ____ **Title:** ____ **E-mail address** ____

**Dept / Affiliation:** ____

***Roles / Responsibilities:***

11. **LOCATION OF RESEARCH. List all locations where data collection will take place.** (School systems, organizations, businesses, buildings and room numbers, servers for web surveys, etc.) **Be as specific as possible. Attach permission letters in** Appendix E.
*(See sample letters at http://www.auburn.edu/research/vpr/ohs/sample.htm)*

The website "www.qualtrics.com" is utilized to deliver the survey and collect data. Participants will enroll in the study through their personal computers or mobile devices.

12. **PARTICIPANTS.**

a. **Describe the participant population you have chosen for this project including inclusion or exclusion criteria for participant selection.**

☐ **Check here if using existing data, describe the population from whom data was collected, & include the # of data files.**

Study participants will be a convenience sample of at least 300 adults over the age of 19, who had worked at least 3 months for a manufacturing organization. Inclusion criteria will be current employees. There are no exclusions based on age, race, gender and other factors.

Supplier companies to Holley Performance Products, Inc. will be contacted with an invitation to participate in this study. American manufacturing companies outside of the Holley supply chain may also be contacted and recruited, as needed. The accepting companies will be asked to provide employee email addresses as a means to send the invitation to these individuals and provide a link to the survey. Employees of Holley Performance Products, Inc. will NOT be participants in this study.

b. **Describe, step-by-step, in layman's terms, all procedures you will use to recruit participants.** *Include in Appendix B a copy of all e-mails, flyers, advertisements, recruiting scripts, invitations, etc., that will be used to invite people to participate. (See sample documents at http://www.auburn.edu/research/vpr/ohs/sample.htm.)*

An electronic survey will be emailed to approximately 700 current employees working in manufacturing companies. Participants will be recruited through the researcher's professional contacts through his employer, Holley Performance Products, Inc. American manufacturing companies outside of this scope may also be recruited, as needed. Written permission has been granted by Holley (Appendix E). The email will contain a description of the purpose of the study and provide a link to the survey website. The information letter will be displayed in the first part of the survey informing potential participants that their participation is completely voluntary and no identifiable information will be collected directly or indirectly.

c. **What is the minimum number of participants you need to validate the study?** 300

**How many participants do you expect to recruit?** 700

**Is there a limit on the number of participants you will include in the study?** ☒ **No** ☐ **Yes – the # is** ________

d. **Describe the type, amount and method of compensation and/or incentives for participants.**

(If no compensation will be given, check here: ☒ )

Select the type of compensation: ☐ Monetary ☐ Incentives

☐ Raffle or Drawing incentive (Include the chances of winning.)

☐ Extra Credit (State the value)

☐ Other

*Description:*

Version Date (date document created): Feb. 7, 2022

13. **PROJECT DESIGN & METHODS.**

a. **Describe, step-by-step, all procedures and methods that will be used to consent participants. If a waiver is being requested, check each waiver you are requesting, describe how the project meets the criteria for the waiver.**

- ☐ **Waiver of Consent (including using existing data)**
- ☒ **Waiver of Documentation of Consent (use of Information Letter)**
- ☐ **Waiver of Parental Permission (for college students)**

Study participation presents minimal risk of harm to the subject and the research involves no procedures requiring consent outside the context of participation in a research study. Potential participants will receive an email that will contain a description of the purpose of the study and provide a link to the survey's website. Potential subjects will be informed that this questionnaire should be completed by the person to whom the email was addressed, and be informed that their participation is completely voluntary and no identifiable information will be collected directly or indirectly. The participant may refuse to take part in the research or exit the survey at any time without penalty.

b. **Describe the research design and methods you will use to address your purpose. Include a clear description of when, where and how you will collect all data for this project.** Include specific information about the participants' time and effort commitment. (*NOTE: Use language that would be understandable to someone who is not familiar with your area of study. Without a complete description of all procedures, the Auburn University IRB will not be able to review this protocol. If additional space is needed for this section, save the information as a .PDF file and insert after page 7 of this form.* )

An electronic survey will be emailed to approximately 700 current employees working in manufacturing companies that supply Holley Performance Products, Inc. Additionally, the survey may be emailed to companies outside of the Holley supply chain, as needed. The email will contain a description of the purpose of the study and provide a link to the survey website. The information letter will be displayed in the first part of the survey. The potential participants will be informed that their participations are completely voluntary and no identifiable information will be collected directly or indirectly.

The survey contains 5 constructs and 30 total questions, and should take approximately 15-20 minutes to complete. The survey items are set up in a first-person perspective would allow for employees at all positions of the organization to answer the questions from their perceptions based on research by Shetty [2], Loyd [3], and Huang [4]. The first construct consists of 5 questions about employees' perspectives on the implementation of Standardization at their work site which mainly asks about if the best way to do job is clearly defined and standardized. The second construct consists of 7 questions about Built-in-Quality which mainly asks about if their companies have processes and procedures to identify defects as they happen at the process and fix problems at the root cause level. The third construct consists of 6 questions about Just-in-Time which asks about if their companies seek to eliminate or reduce batching and work-in-process inventory. The fourth construct consists of 9 questions covering continuous improvement and respect for people and aims to evaluate the degree of making the best of all employees' knowledge, skills, and abilities. These items chose a seven-point Likert scale for the measurement, ranging from 1 (strongly disagree) to 7 (strongly agree). The last construct contains 3 simple fill in the blank questions on indicators representing the desired results of implementation of a Lean production system including First-Pass-Yield, On-Time-Delivery, and Process Downtime. Also, the questionnaire will ask about the participants' demographics including years of service, whether participant is over 19 years old, job responsibility and company size.

The online survey tool website "www.qualtrics.com" is utilized to deliver the survey and collect data. We plan to send out the survey link to the potential participants by email on Monday, August 30, 2021. Participants will enroll in the study through their personal computers or mobile devices. The collected data will be used to develop lean scores for the companies represented. These lean scores will then be tested against safety scores, using regression analysis to determine the association between lean manufacturing and occupational safety/ergonomics.

**13. PROJECT DESIGN & METHODS.** *Continued*

**c. List all data collection instruments used in this project, in the order they appear in Appendix C.**
(e.g., surveys and questionnaires **in the format that will be presented to participants**, educational tests, data collection sheets, interview questions, audio/video taping methods etc.)

Employees of participating companies will receive an email link to an online questionnaire via Qualtrics.

**d. Data analysis: Explain how the data will be analyzed.**

The survey responses will be grouped according to the participants employer company, and scores will be determined from these data in the categories of JIT, standardization and stability, built-in quality, and lean culture. These company lean scores will be paired with the OSHA metrics of TCR, DART, and DAFWII from the same company. These companies will constitute the study population, and regression analysis will be used to determine association between the independent variables (lean scores) and dependent variables (OSHA incident rate scores).

**14. RISKS & DISCOMFORTS: List and describe all of the risks that participants might encounter in this research.** ***If you are using deception in this study, please justify the use of deception and be sure to attach a copy of the debriefing form you plan to use in Appendix D.*** *(Examples of possible risks are in section #6D on page 2)*

Participants may feel slightly distressed to answering some questions as thinking about working experiences. Participation in this survey is voluntary. Participants may refuse to take part in the research or exit the survey at any time without penalty. Participants are free to decline to answer any questions that they do not wish to answer for any reason.

15. **PRECAUTIONS.** Identify and describe all precautions you have taken to eliminate or reduce risks as listed in #14. If the participants can be classified as a "vulnerable" population, please describe additional safeguards that you will use to assure the ethical treatment of these individuals. ***Provide a copy of any emergency plans/procedures and medical referral lists in Appendix D. (Samples can be found online at http://www.auburn.edu/research/vpr/ohs/sample.htm#precautions)***

To minimize the concern of potential subjects, they will be informed that their participation is completely voluntary and no identifiable information (i.e., name, date of birth, social security number, location, IP address) will be collected directly or indirectly. All collected information will be kept strictly confidential. Subjects will be able to terminate their participation at any time by closing the web page of the survey. All the research questions in the questionnaire are directly related to the research aim, and we will not ask any unrelated questions. Since the participants will be anonymous and employed by a different company than the researcher, coercion will not be a risk to the participants.

**If using the Internet or other electronic means to collect data, what confidentiality or security precautions are in place to protect (or not collect) identifiable data? Include protections used during both the collection and transfer of data.**

No identifiable data will be collected directly or indirectly in this study. No IP address will be recorded. Data from the questionnaire will be kept and maintained on "AU Box" storage, which dual authenticated and encrypted.

16. **BENEFITS.**

a. **List all realistic direct benefits participants can expect by participating in this specific study.**
*(Do not include "compensation" listed in #12d.)* Check here if there are no direct benefits to participants. ☒

b. **List all realistic benefits for the general population that may be generated from this study.**

The company lean scores derived from survey responses will be compared to OSHA incidence rate scores from the same company to determine the association between lean method implementation level and occupational safety/ergonomics.

17. **PROTECTION OF DATA.**

a. **Data are collected:**

- ☒ **Anonymously with no direct or indirect coding, link, or awareness of who participated in the study (Skip to e)**
- ☐ **Confidentially, but without a link of participant's data to any identifying information (collected as "confidential" but recorded and analyzed as "anonymous") (Skip to e)**
- ☐ **Confidentially with collection and protection of linkages to identifiable information**

b. **If data are collected with identifiers or as coded or linked to identifying information, describe the identifiers collected and how they are linked to the participant's data.**

c. **Justify your need to code participants' data or link the data with identifying information.**

d. **Describe how and where identifying data and/or code lists will be stored.** (Building, room number?) **Describe how the location where data is stored will be secured in your absence. For electronic data, describe security. If applicable, state specifically where any IRB-approved and participant-signed consent documents will be kept on campus for 3 years after the study ends.**

e. **Describe how and where the data will be stored** (e.g., hard copy, audio cassette, electronic data, etc.), **and how the location where data is stored is separated from identifying data and will be secured in your absence. For electronic data, describe security**

Data from the questionnaire will be kept and maintained on "AU Box" and accessible only to research personnel.

f. **Who will have access to participants' data?**
(*The faculty advisor should have full access and be able to produce the data in the case of a federal or institutional audit.*)

Only the research team members who are listed under the Key personnel.

g. **When is the latest date that identifying information or links will be retained and how will that information or links be destroyed?**
(Check here if only anonymous data will be retained ☒ )

CITI Training Certificates

## COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)
### COMPLETION REPORT - PART 1 OF 2
### COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Joel Brawner (ID: 8100601)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** jgb0018@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** 615-633-7727

- **Curriculum Group:** IRB # 2 Social and Behavioral Emphasis - AU Personnel - Basic/Refresher
- **Course Learner Group:** IRB # 2 Social and Behavioral Emphasis - AU Personnel
- **Stage:** Stage 1 - Basic Course
- **Description:** Choose this group to satisfy CITI training requirements for Key Personnel (including AU Faculty, Staff and Students) and Faculty Advisors involved primarily in Social/Behavioral Research with human subjects.

- **Record ID:** 31550416
- **Completion Date:** 13-May-2019
- **Expiration Date:** 12-May-2022
- **Minimum Passing:** 80
- **Reported Score*:** 100

| REQUIRED AND ELECTIVE MODULES ONLY | DATE COMPLETED | SCORE |
|---|---|---|
| Belmont Report and Its Principles (ID: 1127) | 10-May-2019 | 3/3 (100%) |
| The Federal Regulations - SBE (ID: 502) | 10-May-2019 | 5/5 (100%) |
| Assessing Risk - SBE (ID: 503) | 13-May-2019 | 5/5 (100%) |
| Informed Consent - SBE (ID: 504) | 13-May-2019 | 5/5 (100%) |
| Privacy and Confidentiality - SBE (ID: 505) | 13-May-2019 | 5/5 (100%) |
| Students in Research (ID: 1321) | 13-May-2019 | 5/5 (100%) |
| Unanticipated Problems and Reporting Requirements in Social and Behavioral Research (ID: 14928) | 13-May-2019 | 5/5 (100%) |

**For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.**

**Verify at:** www.citiprogram.org/verify/?k969366ab-77b0-4aca-9ae9-142561329714-31550416

**Collaborative Institutional Training Initiative (CITI Program)**
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

# COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

## COMPLETION REPORT - PART 2 OF 2
## COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Joel Brawner (ID: 8100601)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** jgb0018@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** 615-633-7727

- **Curriculum Group:** IRB # 2 Social and Behavioral Emphasis - AU Personnel - Basic/Refresher
- **Course Learner Group:** IRB # 2 Social and Behavioral Emphasis - AU Personnel
- **Stage:** Stage 1 - Basic Course
- **Description:** Choose this group to satisfy CITI training requirements for Key Personnel (including AU Faculty, Staff and Students) and Faculty Advisors involved primarily in Social/Behavioral Research with human subjects.

- **Record ID:** 31550416
- **Report Date:** 01-Jun-2021
- **Current Score**:** 100

| REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES | MOST RECENT | SCORE |
|---|---|---|
| Students in Research (ID: 1321) | 13-May-2019 | 5/5 (100%) |
| Belmont Report and Its Principles (ID: 1127) | 10-May-2019 | 3/3 (100%) |
| The Federal Regulations - SBE (ID: 502) | 10-May-2019 | 5/5 (100%) |
| Assessing Risk - SBE (ID: 503) | 13-May-2019 | 5/5 (100%) |
| Informed Consent - SBE (ID: 504) | 13-May-2019 | 5/5 (100%) |
| Privacy and Confidentiality - SBE (ID: 505) | 13-May-2019 | 5/5 (100%) |
| Unanticipated Problems and Reporting Requirements in Social and Behavioral Research (ID: 14928) | 13-May-2019 | 5/5 (100%) |

**For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.**

**Verify at:** www.citiprogram.org/verify/?k969366ab-77b0-4aca-9ae9-142561329714-31550416

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Email: support@citiprogram.org
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# COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

## COMPLETION REPORT - PART 1 OF 2
## COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Joel Brawner (ID: 8100601)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** jgb0018@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** 615-633-7727

- **Curriculum Group:** IRB Additional Modules
- **Course Learner Group:** Workers as Research Subjects - A Vulnerable Population
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 31550415
- **Completion Date:** 01-Jun-2021
- **Expiration Date:** 31-May-2024
- **Minimum Passing:** 80
- **Reported Score*:** 100

| REQUIRED AND ELECTIVE MODULES ONLY | DATE COMPLETED | SCORE |
|---|---|---|
| Vulnerable Subjects - Research Involving Workers/Employees (ID: 483) | 01-Jun-2021 | 4/4 (100%) |

**For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.**

**Verify at:** www.citiprogram.org/verify/?k1330fbb6-074f-4975-b00d-fc452ebb9411-31550415

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**COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)**

**COMPLETION REPORT - PART 2 OF 2**

**COURSEWORK TRANSCRIPT****

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Joel Brawner (ID: 8100601)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** jgb0018@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** 615-633-7727

- **Curriculum Group:** IRB Additional Modules
- **Course Learner Group:** Workers as Research Subjects - A Vulnerable Population
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 31550415
- **Report Date:** 01-Jun-2021
- **Current Score**:** 100

| REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES | MOST RECENT | SCORE |
|---|---|---|
| Vulnerable Subjects - Research Involving Workers/Employees (ID: 483) | 01-Jun-2021 | 4/4 (100%) |

**For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.**

**Verify at:** www.citiprogram.org/verify/?k1330fbb6-074f-4975-b00d-fc452ebb9411-31550415

**Collaborative Institutional Training Initiative (CITI Program)**
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Phone: 888-529-5929
Web: https://www.citiprogram.org

CITI PROGRAM

Completion Date 13-May-2019
Expiration Date 12-May-2022
Record ID 31550416

This is to certify that:

**Joel Brawner**

Has completed the following CITI Program course:

Not valid for renewal of certification through CME.

**IRB # 2 Social and Behavioral Emphasis - AU Personnel - Basic/Refresher**
(Curriculum Group)
**IRB # 2 Social and Behavioral Emphasis - AU Personnel**
(Course Learner Group)
**1 - Basic Course**
(Stage)

Under requirements set by:

**Auburn University**

CITI
Collaborative Institutional Training Initiative

Verify at www.citiprogram.org/verify/?w766e98be-5a00-462f-8f7b-47a85db601e2-31550416

CITI PROGRAM

| | |
|---|---|
| Completion Date | 01-Jun-2021 |
| Expiration Date | 31-May-2024 |
| Record ID | 31550415 |

This is to certify that:

**Joel Brawner**

Has completed the following CITI Program course:

Not valid for renewal of certification through CME.

**IRB Additional Modules**
(Curriculum Group)
**Workers as Research Subjects - A Vulnerable Population**
(Course Learner Group)
**1 - Basic Course**
(Stage)

Under requirements set by:

**Auburn University**

CITI
Collaborative Institutional Training Initiative

Verify at www.citiprogram.org/verify/?wfb5d7f9b-176e-4cfc-820b-b2f002f5822d-31550415

CITI PROGRAM

| | |
|---|---|
| Completion Date | 13-May-2021 |
| Expiration Date | 12-May-2024 |
| Record ID | 39919746 |

This is to certify that:

**Gregory Harris**

Has completed the following CITI Program course:

Not valid for renewal of certification through CME.

**IRB #1 Health Science Emphasis - AU Personnel - Basic/Refresher**
(Curriculum Group)
**IRB #1 Health Science Emphasis - AU Personnel**
(Course Learner Group)
**1 - Basic Course**
(Stage)

Under requirements set by:

**Auburn University**

CITI
Collaborative Institutional Training Initiative

Verify at www.citiprogram.org/verify/?w0c25acb5-12cc-4fc2-8a98-3eb0ac099bcf-39919746

IRB Modification—Appendix A: References

[1] Z. Huang, G. Harris, and N. Loyd, "An improved lean assessment based on employee perception," Journal of Manufacturing Technology Management, vol. Ahead-of-Print, no. Ahead-of-Print, 2021.

[2] S. K. Shetty, "A Proposed New Model to understand Lean Implementation using Employee Perception," Ph.D., The University of Alabama in Huntsville, 2011.

[3] N. Loyd, "Analysis ofthe use of employee perception to assess the implementation of lean based on the Toyota production system and Toyota way," Ph.D., The University of Alabama in Huntsville, 2017.

[4] Z. Huang, "Study of the Use of Employee Perception to Assess Lean Adoption Based on the Toyota Production System and Toyota Way Model in the Chinese Automobile Industry," Ph.D. Doctoral Dissertation, Auburn University, 2019.

IRB Modification—Appendix B: Recruitment Email

You are invited to participate in a research study to evaluate the association between the adoption level of lean manufacturing methods and occupational safety/ergonomic incidence rates.

This study is being conducted by Joel Brawner (doctoral student) under the supervision of Dr. Gregory Harris, Ph.D., P.E. (Associate Professor) in the Auburn University's Department of Industrial and Systems Engineering. You were selected as a possible participant because you were adult over the age of 19, the youngest legal age for human research subjects, who had worked at least 3 months for an organization that had implemented Lean for at least a year.

Your participation is completely voluntary. If you decide to participate in this research study, you will be asked to complete a short electronic survey about your perspective on the implementation of Lean production system at your work site covering Standardization, Built-in-Quality, Just-in-Time and culture. Your total time commitment will be approximately 15-20 minutes.

The risks associated with participating in this study are minimal. No identifiable data will be collected directly or indirectly, no IP address will be recorded, and all your responses will be kept strictly confidential. You may feel slightly distressed to answering some questions as you think about your working experiences. You may refuse to take part in the research or exit the survey at any time without penalty. You are free to decline to answer any question you do not wish to answer for any reason. Your decision will not affect your relationship with Auburn University, the Department of Industrial and Systems Engineering or the researcher.

If you have questions about this study, please contact Joel Brawner at jgb0018@auburn.edu or Dr. Gregory Harris, Ph.D., P.E. at greg.harris@auburn.edu.

The Auburn University Institutional Review Board has approved this document for use from __________ to _________. Protocol #________.

LINK TO THE SURVEY

Yours truly,

Joel Brawner
Ph.D. Candidate
Auburn University, Industrial and Systems Engineering Department
3333 Shelby Center
jgb0018@auburn.edu
615-633-7727

IRB Modification—Appendix C: Survey Content

AUBURN UNIVERSITY

SAMUEL GINN COLLEGE OF ENGINEERING
INDUSTRIAL AND SYSTEMS ENGINEERING

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

**INFORMATION LETTER**
**for a Research Study entitled**
**"The effects of lean manufacturing on occupational safety and ergonomics"**

You are invited to participate in a research study to evaluate the association between the adoption level of lean manufacturing methods and occupational safety/ergonomic incidence rates. The study is being conducted by Joel Brawner (doctoral student) under the supervision of Dr. Gregory Harris, Ph.D., P.E. (Associate Professor) in the Auburn University's Department of Industrial and Systems Engineering. You were selected as a possible participant because you were adult over the age of 19, the youngest legal age for human research subjects, who had worked at least 3 months for a manufacturing organization.

**What will be involved if you participate?** Your participation is completely voluntary. If you decide to participate in this research study, you will be asked to complete a short electronic survey. Your total time commitment will be approximately 15-20 minutes.

**Are there any risks or discomforts?** The risks associated with participating in this study are minimal. No identifiable data will be collected directly or indirectly in this study and all your responses will be kept strictly confidential. You may feel slightly distressed to answering some questions as you think about your working experiences. Your participation in this survey is voluntary. You may refuse to take part in the research or exit the survey at any time without penalty. You are free to decline to answer any question you do not wish to answer for any reason.

**Are there any benefits to yourself or others?** You will not receive any direct benefit from participating in this study. However, your responses may help us learn more about the effects of lean manufacturing methods on occupational safety and ergonomics.

SHELBY CENTER FOR ENGINEERING TECHNOLOGY
SUITE 3301
AUBURN, AL 36849-5346

TELEPHONE
334-844-4340

FAX:
334-844-1381

www.auburn.edu

AUBURN UNIVERSITY

SAMUEL GINN COLLEGE OF ENGINEERING
INDUSTRIAL AND SYSTEMS ENGINEERING

**Will you receive compensation for participating?** No compensation will be provided for your participation.

**Are there any costs?** There are no costs (e.g., fees) associated with participation. If you choose not to participate, your decision will not affect your relationship with Auburn University, the Department of Industrial and Systems Engineering or the researcher.

**No identifiable data will be collected directly or indirectly in this study and** any data obtained in connection with this study will be kept strictly confidential. Information collected through your participation may be used to fulfill an educational requirement, published in a professional journal, or presented at a professional meeting, etc.

**If you have questions about this study,** please contact Joel Brawner at jgb0018@auburn.edu or Dr. Gregory Harris, Ph.D., P.E. at greg.harris@auburn.edu.

**If you have questions about your rights as a research participant,** you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. BY CLICKING NEXT TO CONTINUE TO THE SURVEY, YOU ARE INDICATING YOU HAVE READ THE INFORMATION LETTER AND ARE WILLING TO PARTICIPATE.

**The Auburn University Institutional Review Board has approved this document for use from __________ to ________. Protocol #_______.**

SHELBY CENTER FOR
ENGINEERING TECHNOLOGY
SUITE 3301
AUBURN, AL 36849-5346

TELEPHONE
334-844-4340

FAX:
334-844-1381

www.auburn.edu

**Lean Assessment Survey**

What is your age?

How many years have you worked for your current company?

What is your job responsibility

- Front line
- Team leader / Supervisor
- Management
- Administration
- Quality
- Engineering
- Finance

Company Size (total employees at the site you work at)?

- 0-10
- 11-50
- 51-100
- 101-200

- 201-300
- 301-500
- Over 500

My company has a well-defined system for workplace organization.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

The best way to do my job is clearly defined and standardized.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

A specific training method is used to introduce, progress, and cross-train employees on their jobs.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

In my workspace, normal operating conditions - such as production status, tool and material locations, and equipment status - are visually obvious.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company has a well-defined system to measure process downtime.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company has well-defined processes and procedures to identify defects as they happen at the process.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Defect rates are accurately measured at my process.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company seeks to fix problems at the root cause level.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

When mistakes or defects happen, there is a well-defined system to provide feedback to the source of the mistake.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Employees at my company are trained to use a well-defined process to solve problems.

- Strongly Disagree

- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company views problems as opportunities and we stop and learn from them.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Effective error-proofing techniques are used at my company.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company seeks to eliminate or reduce batching and work-in-process inventory (WIP).

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree

- Agree
- Strongly Agree

Our facility layout allows for work to flow easily from process to process.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Work in my company is well balanced to meet a specific daily goal.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Parts are delivered to the production line in the quantities that are needed, when they are needed.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Work is always scheduled visually based on the next process's needs.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company aggressively seeks to reduce inventory.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

I know which steps in my job are value-added or non-value-added.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Decisions at my company are always based on relevant facts and data.

- Strongly Disagree
- Disagree

- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Management at my company treats me with respect and I feel I can safely express my opinions.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

I understand my company's strategic vision and mission.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company values ideas for improvement from all employees.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree

- Agree
- Strongly Agree

My company values knowledge, skills, and abilities from all employees.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

Teamwork is practiced at my company; everyone is expected and willing to help and hold each other accountable.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My manager actively works with me to improve my process.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

My company provides good opportunities for my growth and development.

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Agree
- Strongly Agree

What is the % Process Downtime in your workspace?

What is the First Pass Yield (%) in your workspace?

What is the On-time Delivery Rate (%) in your workspace?

Powered by Qualtrics

IRB Modification—Appendix D: Permission Letter

Holley Performance Products, Inc.

1801 Russellville Rd 42101, Bowling Green, KY 42101
www.holley.com, (270) 782-2900 Fax (270) 745-9545

August 13, 2021

Joel Brawner
Manufacturing/Industrial Engineering Manager
Holley Performance Products, Inc.
1801 Russellville Road
Bowling Green, KY 42101

Dear Joel:

Concerning your desire to survey companies within the Holley supply chain to determine their level of lean adoption, we are happy to cooperate. Holley will provide contact information for the companies you wish to survey and authorize you to communicate with these representatives as needed. The conditions agreed upon are as follows:

1. Holley Performance Products, Inc. (Holley) will have no access to the collected data.
2. Holley will be provided a report with the aggregate findings at the end of the study.
3. Sharing of information that can be used to identify a specific company or employee is strictly prohibited.
4. Collected data will be used for academic purposes only, unless otherwise authorized.
5. Holley reserves the right to revoke or alter this authorization in the future with or without cause.
6. Start date for and duration of surveying activities will be communicated to me before these activities begin.

Our hope is that the data collection procedures established in your effort will aid us in conducting supplier surveys in the future.

We wish you the best of luck in your efforts.

Yours truly,

Dan Rowe
Vice President, Supply Chain Management
e: danielrowe@holley.com
p: (270) 782-2900 ext. 1402 | www.holley.com

**Appendix C: Central Tendency Measures for Responses to Individual Survey Statements**

**Central Tendency Measures for Responses to Individual Survey Statements**

| Construct | Statement | Mean | Median | Mode |
|---|---|---|---|---|
| Standardization & Stability | S1 | 4.8 | 5 | 6 |
| | S2 | 5.2 | 6 | 6 |
| | S3 | 4.6 | 5 | 5 |
| | S4 | 5.3 | 6 | 6 |
| | S5 | 4.7 | 5 | 4 |
| Quality | Q1 | 5.0 | 5 | 6 |
| | Q2 | 5.0 | 5 | 6 |
| | Q3 | 4.7 | 5 | 6 |
| | Q4 | 4.7 | 5 | 6 |
| | Q5 | 4.7 | 5 | 6 |
| | Q6 | 4.8 | 5 | 6 |
| | Q7 | 4.7 | 5 | 6 |
| Just-in-Time | J1 | 4.8 | 5 | 4 |
| | J2 | 5.0 | 5 | 6 |
| | J3 | 5.1 | 5 | 6 |
| | J4 | 4.7 | 5 | 6 |
| | J5 | 5.0 | 5 | 6 |
| | J6 | 4.6 | 4 | 4 |
| Lean Culture | C1 | 5.1 | 5 | 6 |
| | C2 | 4.8 | 5 | 6 |
| | C3 | 5.0 | 6 | 7 |
| | C4 | 5.2 | 6 | 6 |
| | C5 | 4.7 | 5 | 6 |
| | C6 | 4.8 | 5 | 6 |
| | C7 | 5.1 | 6 | 6 |
| | C8 | 5.1 | 5 | 6 |
| | C9 | 4.6 | 5 | 4 |

# Appendix D: Facility Level Backward-Elimination Multi-Regression—SPSS Output

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | S&S , JIT , Quality , Culture[b] | . | Enter |
| 2 | . | Quality | Backward (criterion: Probability of F-to-remove >= .100). |
| 3 | . | S&S | Backward (criterion: Probability of F-to-remove >= .100). |

a. Dependent Variable: TCRsc

b. All requested variables entered.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .730[a] | .533 | .222 | 1.49493 |
| 2 | .729[b] | .532 | .332 | 1.38535 |
| 3 | .720[c] | .518 | .397 | 1.31552 |

a. Predictors: (Constant), S&S , JIT , Quality , Culture

b. Predictors: (Constant), S&S , JIT , Culture

c. Predictors: (Constant), JIT , Culture

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 15.300 | 4 | 3.825 | 1.712 | .265[b] |
| | Residual | 13.409 | 6 | 2.235 | | |
| | Total | 28.709 | 10 | | | |
| 2 | Regression | 15.275 | 3 | 5.092 | 2.653 | .130[c] |
| | Residual | 13.434 | 7 | 1.919 | | |
| | Total | 28.709 | 10 | | | |
| 3 | Regression | 14.865 | 2 | 7.432 | 4.295 | .054[d] |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Residual | 13.845 | 8 | 1.731 | | |
| | Total | 28.709 | 10 | | | |

a. Dependent Variable: TCRsc

b. Predictors: (Constant), S&S , JIT , Quality , Culture

c. Predictors: (Constant), S&S , JIT , Culture

d. Predictors: (Constant), JIT , Culture

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 6.025 | 8.038 | | .750 | .482 |
| | Quality | -.281 | 2.629 | -.058 | -.107 | .919 |
| | JIT | -3.611 | 2.358 | -.779 | -1.531 | .177 |
| | Culture | 3.818 | 1.655 | 1.311 | 2.307 | .061 |
| | S&S | -1.005 | 2.846 | -.215 | -.353 | .736 |
| 2 | (Constant) | 5.800 | 7.187 | | .807 | .446 |
| | JIT | -3.687 | 2.085 | -.796 | -1.769 | .120 |
| | Culture | 3.783 | 1.504 | 1.299 | 2.515 | .040 |
| | S&S | -1.123 | 2.430 | -.240 | -.462 | .658 |
| 3 | (Constant) | 4.039 | 5.789 | | .698 | .505 |
| | JIT | -4.051 | 1.833 | -.874 | -2.211 | .058 |
| | Culture | 3.372 | 1.152 | 1.158 | 2.928 | .019 |

a. Dependent Variable: TCRsc

**Excluded Variables[a]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics Tolerance |
|---|---|---|---|---|---|---|
| 2 | Quality | -.058[b] | -.107 | .919 | -.044 | .262 |
| 3 | Quality | -.133[c] | -.283 | .785 | -.106 | .309 |
| | S&S | -.240[c] | -.462 | .658 | -.172 | .247 |

a. Dependent Variable: TCRsc

b. Predictors in the Model: (Constant), S&S , JIT , Culture

c. Predictors in the Model: (Constant), JIT , Culture

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | S&S , JIT , Quality , Culture[b] | . | Enter |
| 2 | . | Quality | Backward (criterion: Probability of F-to-remove >= .100). |
| 3 | . | S&S | Backward (criterion: Probability of F-to-remove >= .100). |

a. Dependent Variable: DARTsc

b. All requested variables entered.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .807[a] | .652 | .420 | .85889 |
| 2 | .806[b] | .650 | .500 | .79726 |
| 3 | .785[c] | .616 | .520 | .78114 |

a. Predictors: (Constant), S&S , JIT , Quality , Culture

b. Predictors: (Constant), S&S , JIT , Culture

c. Predictors: (Constant), JIT , Culture

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 8.286 | 4 | 2.072 | 2.808 | .125[b] |
| | Residual | 4.426 | 6 | .738 | | |
| | Total | 12.713 | 10 | | | |
| 2 | Regression | 8.263 | 3 | 2.754 | 4.333 | .050[c] |
| | Residual | 4.449 | 7 | .636 | | |
| | Total | 12.713 | 10 | | | |
| 3 | Regression | 7.831 | 2 | 3.916 | 6.417 | .022[d] |
| | Residual | 4.881 | 8 | .610 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Total | | 12.713 | 10 | | | |

a. Dependent Variable: DARTsc

b. Predictors: (Constant), S&S , JIT , Quality , Culture

c. Predictors: (Constant), S&S , JIT , Culture

d. Predictors: (Constant), JIT , Culture

**Coefficients[a]**

| Model | | Unstandardized Coefficients B | Unstandardized Coefficients Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 7.757 | 4.618 | | 1.680 | .144 |
| | Quality | -.268 | 1.511 | -.083 | -.177 | .865 |
| | JIT | -3.017 | 1.355 | -.978 | -2.227 | .068 |
| | Culture | 2.860 | .951 | 1.476 | 3.008 | .024 |
| | S&S | -1.040 | 1.635 | -.335 | -.636 | .548 |
| 2 | (Constant) | 7.543 | 4.136 | | 1.824 | .111 |
| | JIT | -3.089 | 1.200 | -1.002 | -2.575 | .037 |
| | Culture | 2.827 | .866 | 1.459 | 3.266 | .014 |
| | S&S | -1.153 | 1.398 | -.371 | -.825 | .437 |
| 3 | (Constant) | 5.736 | 3.437 | | 1.669 | .134 |
| | JIT | -3.463 | 1.088 | -1.123 | -3.182 | .013 |
| | Culture | 2.405 | .684 | 1.241 | 3.516 | .008 |

a. Dependent Variable: DARTsc

**Excluded Variables[a]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics Tolerance |
|---|---|---|---|---|---|---|
| 2 | Quality | -.083[b] | -.177 | .865 | -.072 | .262 |
| 3 | Quality | -.200[c] | -.482 | .645 | -.179 | .309 |
| | S&S | -.371[c] | -.825 | .437 | -.298 | .247 |

a. Dependent Variable: DARTsc

b. Predictors in the Model: (Constant), S&S , JIT , Culture

c. Predictors in the Model: (Constant), JIT , Culture

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | S&S , JIT , Quality , Culture[b] | . | Enter |
| 2 | . | Quality | Backward (criterion: Probability of F-to-remove >= .100). |
| 3 | . | S&S | Backward (criterion: Probability of F-to-remove >= .100). |

a. Dependent Variable: DAFWIIsc

b. All requested variables entered.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .745[a] | .554 | .257 | .37495 |
| 2 | .740[b] | .548 | .354 | .34964 |
| 3 | .726[c] | .528 | .409 | .33440 |

a. Predictors: (Constant), S&S , JIT , Quality , Culture

b. Predictors: (Constant), S&S , JIT , Culture

c. Predictors: (Constant), JIT , Culture

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1.050 | 4 | .262 | 1.867 | .236[b] |
| | Residual | .844 | 6 | .141 | | |
| | Total | 1.893 | 10 | | | |
| 2 | Regression | 1.038 | 3 | .346 | 2.829 | .116[c] |
| | Residual | .856 | 7 | .122 | | |
| | Total | 1.893 | 10 | | | |
| 3 | Regression | .999 | 2 | .499 | 4.466 | .050[d] |
| | Residual | .895 | 8 | .112 | | |

| Total | 1.893 | 10 | | | |
|---|---|---|---|---|---|

a. Dependent Variable: DAFWIIsc

b. Predictors: (Constant), S&S , JIT , Quality , Culture

c. Predictors: (Constant), S&S , JIT , Culture

d. Predictors: (Constant), JIT , Culture

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 2.006 | 2.016 | | .995 | .358 |
| | Quality | -.194 | .660 | -.157 | -.295 | .778 |
| | JIT | -1.306 | .591 | -1.097 | -2.207 | .069 |
| | Culture | .754 | .415 | 1.008 | 1.816 | .119 |
| | S&S | .427 | .714 | .356 | .599 | .571 |
| 2 | (Constant) | 1.850 | 1.814 | | 1.020 | .342 |
| | JIT | -1.358 | .526 | -1.141 | -2.581 | .036 |
| | Culture | .730 | .380 | .976 | 1.923 | .096 |
| | S&S | .346 | .613 | .288 | .564 | .591 |
| 3 | (Constant) | 2.392 | 1.471 | | 1.625 | .143 |
| | JIT | -1.246 | .466 | -1.047 | -2.674 | .028 |
| | Culture | .856 | .293 | 1.145 | 2.925 | .019 |

a. Dependent Variable: DAFWIIsc

**Excluded Variables[a]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics |
|---|---|---|---|---|---|---|
| | | | | | | Tolerance |
| 2 | Quality | -.157[b] | -.295 | .778 | -.119 | .262 |
| 3 | Quality | -.033[c] | -.071 | .946 | -.027 | .309 |
| | S&S | .288[c] | .564 | .591 | .208 | .247 |

a. Dependent Variable: DAFWIIsc

b. Predictors in the Model: (Constant), S&S , JIT , Culture

c. Predictors in the Model: (Constant), JIT , Culture

**Appendix E: Individual Level Backward-Elimination Multi-Regression—SPSS Output**

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | S&S, Culture, JIT, Quality[b] | . | Enter |
| 2 | . | Quality | Backward (criterion: Probability of F-to-remove >= .100). |
| 3 | . | S&S | Backward (criterion: Probability of F-to-remove >= .100). |

a. Dependent Variable: TCRsc

b. All requested variables entered.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .243[a] | .059 | .045 | 1.8282561 |
| 2 | .243[b] | .059 | .049 | 1.8248344 |
| 3 | .232[c] | .054 | .047 | 1.8263368 |

a. Predictors: (Constant), S&S, Culture, JIT, Quality

b. Predictors: (Constant), S&S, Culture, JIT

c. Predictors: (Constant), Culture, JIT

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 55.850 | 4 | 13.963 | 4.177 | .003[b] |
| | Residual | 889.110 | 266 | 3.343 | | |
| | Total | 944.960 | 270 | | | |
| 2 | Regression | 55.845 | 3 | 18.615 | 5.590 | <.001[c] |
| | Residual | 889.115 | 267 | 3.330 | | |
| | Total | 944.960 | 270 | | | |
| 3 | Regression | 51.045 | 2 | 25.522 | 7.652 | <.001[d] |
| | Residual | 893.916 | 268 | 3.336 | | |
| | Total | 944.960 | 270 | | | |

a. Dependent Variable: TCRsc

b. Predictors: (Constant), S&S, Culture, JIT, Quality

c. Predictors: (Constant), S&S, Culture, JIT

d. Predictors: (Constant), Culture, JIT

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | t | Sig. |
| 1 | (Constant) | .777 | .480 | | 1.619 | .107 |
| | Quality | -.008 | .194 | -.006 | -.039 | .969 |
| | JIT | -.361 | .182 | -.232 | -1.979 | .049 |
| | Culture | .584 | .152 | .429 | 3.832 | <.001 |
| | S&S | -.164 | .159 | -.115 | -1.028 | .305 |
| 2 | (Constant) | .779 | .475 | | 1.642 | .102 |
| | JIT | -.364 | .166 | -.233 | -2.186 | .030 |
| | Culture | .582 | .143 | .428 | 4.071 | <.001 |
| | S&S | -.167 | .139 | -.118 | -1.201 | .231 |
| 3 | (Constant) | .665 | .465 | | 1.429 | .154 |
| | JIT | -.445 | .152 | -.285 | -2.920 | .004 |
| | Culture | .518 | .133 | .381 | 3.901 | <.001 |

a. Dependent Variable: TCRsc

**Excluded Variables[a]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics Tolerance |
|---|---|---|---|---|---|---|
| 2 | Quality | -.006[b] | -.039 | .969 | -.002 | .176 |
| 3 | Quality | -.076[c] | -.616 | .538 | -.038 | .230 |
| | S&S | -.118[c] | -1.201 | .231 | -.073 | .368 |

a. Dependent Variable: TCRsc

b. Predictors in the Model: (Constant), S&S, Culture, JIT

c. Predictors in the Model: (Constant), Culture, JIT

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | S&S, Culture, JIT, Quality[b] | . | Enter |
| 2 | . | Quality | Backward (criterion: Probability of F-to-remove >= .100). |
| 3 | . | S&S | Backward (criterion: Probability of F-to-remove >= .100). |

a. Dependent Variable: DARTsc

b. All requested variables entered.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .269[a] | .072 | .058 | 1.1554286 |
| 2 | .269[b] | .072 | .062 | 1.1532859 |
| 3 | .262[c] | .069 | .062 | 1.1534276 |

a. Predictors: (Constant), S&S, Culture, JIT, Quality

b. Predictors: (Constant), S&S, Culture, JIT

c. Predictors: (Constant), Culture, JIT

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 27.672 | 4 | 6.918 | 5.182 | <.001[b] |
| | Residual | 355.114 | 266 | 1.335 | | |
| | Total | 382.786 | 270 | | | |
| 2 | Regression | 27.658 | 3 | 9.219 | 6.931 | <.001[c] |
| | Residual | 355.128 | 267 | 1.330 | | |
| | Total | 382.786 | 270 | | | |
| 3 | Regression | 26.240 | 2 | 13.120 | 9.862 | <.001[d] |
| | Residual | 356.546 | 268 | 1.330 | | |
| | Total | 382.786 | 270 | | | |

a. Dependent Variable: DARTsc

b. Predictors: (Constant), S&S, Culture, JIT, Quality

c. Predictors: (Constant), S&S, Culture, JIT

d. Predictors: (Constant), Culture, JIT

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .591 | .303 | | 1.950 | .052 |
| | Quality | -.013 | .123 | -.015 | -.103 | .918 |
| | JIT | -.297 | .115 | -.299 | -2.577 | .011 |
| | Culture | .411 | .096 | .474 | 4.263 | <.001 |
| | S&S | -.085 | .101 | -.095 | -.850 | .396 |
| 2 | (Constant) | .596 | .300 | | 1.985 | .048 |
| | JIT | -.302 | .105 | -.304 | -2.869 | .004 |
| | Culture | .407 | .090 | .470 | 4.507 | <.001 |
| | S&S | -.091 | .088 | -.100 | -1.032 | .303 |
| 3 | (Constant) | .533 | .294 | | 1.815 | .071 |
| | JIT | -.346 | .096 | -.349 | -3.594 | <.001 |
| | Culture | .373 | .084 | .430 | 4.440 | <.001 |

a. Dependent Variable: DARTsc

**Excluded Variables[a]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics Tolerance |
|---|---|---|---|---|---|---|
| 2 | Quality | -.015[b] | -.103 | .918 | -.006 | .176 |
| 3 | Quality | -.073[c] | -.591 | .555 | -.036 | .230 |
| | S&S | -.100[c] | -1.032 | .303 | -.063 | .368 |

a. Dependent Variable: DARTsc

b. Predictors in the Model: (Constant), S&S, Culture, JIT

c. Predictors in the Model: (Constant), Culture, JIT

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | S&S, Culture, JIT, Quality[b] | . | Enter |
| 2 | . | Quality | Backward (criterion: Probability of F-to-remove >= .100). |
| 3 | . | S&S | Backward (criterion: Probability of F-to-remove >= .100). |
| 4 | . | JIT | Backward (criterion: Probability of F-to-remove >= .100). |
| 5 | . | Culture | Backward (criterion: Probability of F-to-remove >= .100). |

a. Dependent Variable: DAFWIIsc

b. All requested variables entered.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .138[a] | .019 | .004 | .4823856 |
| 2 | .133[b] | .018 | .007 | .4818422 |
| 3 | .130[c] | .017 | .010 | .4810992 |
| 4 | .089[d] | .008 | .004 | .4824037 |
| 5 | .000[e] | .000 | .000 | .4834305 |

a. Predictors: (Constant), S&S, Culture, JIT, Quality

b. Predictors: (Constant), S&S, Culture, JIT

c. Predictors: (Constant), Culture, JIT

d. Predictors: (Constant), Culture

e. Predictor: (constant)

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1.203 | 4 | .301 | 1.293 | .273[b] |
| | Residual | 61.897 | 266 | .233 | | |
| | Total | 63.100 | 270 | | | |
| 2 | Regression | 1.110 | 3 | .370 | 1.594 | .191[c] |
| | Residual | 61.990 | 267 | .232 | | |
| | Total | 63.100 | 270 | | | |
| 3 | Regression | 1.070 | 2 | .535 | 2.311 | .101[d] |
| | Residual | 62.030 | 268 | .231 | | |
| | Total | 63.100 | 270 | | | |
| 4 | Regression | .500 | 1 | .500 | 2.151 | .144[e] |
| | Residual | 62.600 | 269 | .233 | | |
| | Total | 63.100 | 270 | | | |
| 5 | Regression | .000 | 0 | .000 | . | .[f] |
| | Residual | 63.100 | 270 | .234 | | |
| | Total | 63.100 | 270 | | | |

a. Dependent Variable: DAFWIIsc

b. Predictors: (Constant), S&S, Culture, JIT, Quality

c. Predictors: (Constant), S&S, Culture, JIT

d. Predictors: (Constant), Culture, JIT

e. Predictors: (Constant), Culture

f. Predictor: (constant)

**Coefficients[a]**

| Model | | Unstandardized Coefficients B | Unstandardized Coefficients Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | .460 | .127 | | 3.634 | <.001 |
| | Quality | -.032 | .051 | -.091 | -.631 | .528 |
| | JIT | -.058 | .048 | -.144 | -1.207 | .229 |
| | Culture | .078 | .040 | .221 | 1.933 | .054 |
| | S&S | .028 | .042 | .077 | .671 | .503 |
| 2 | (Constant) | .471 | .125 | | 3.754 | <.001 |
| | JIT | -.070 | .044 | -.175 | -1.601 | .111 |
| | Culture | .069 | .038 | .196 | 1.829 | .068 |
| | S&S | .015 | .037 | .042 | .417 | .677 |
| 3 | (Constant) | .481 | .123 | | 3.923 | <.001 |
| | JIT | -.063 | .040 | -.156 | -1.569 | .118 |
| | Culture | .075 | .035 | .213 | 2.139 | .033 |
| 4 | (Constant) | .390 | .108 | | 3.601 | <.001 |
| | Culture | .031 | .021 | .089 | 1.466 | .144 |
| 5 | (Constant) | .543 | .029 | | 18.487 | <.001 |

a. Dependent Variable: DAFWIIsc

**Excluded Variables[a]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics Tolerance |
|---|---|---|---|---|---|---|
| 2 | Quality | -.091[b] | -.631 | .528 | -.039 | .176 |
| 3 | Quality | -.044[c] | -.350 | .727 | -.021 | .230 |
| | S&S | .042[c] | .417 | .677 | .026 | .368 |
| 4 | Quality | -.121[d] | -1.137 | .257 | -.069 | .324 |
| | S&S | -.023[d] | -.252 | .801 | -.015 | .440 |
| | JIT | -.156[d] | -1.569 | .118 | -.095 | .370 |
| 5 | Quality | .034[e] | .558 | .577 | .034 | 1.000 |
| | S&S | .057[e] | .928 | .354 | .057 | 1.000 |
| | JIT | .013[e] | .212 | .832 | .013 | 1.000 |
| | Culture | .089[e] | 1.466 | .144 | .089 | 1.000 |

a. Dependent Variable: DAFWIIsc

b. Predictors in the Model: (Constant), S&S, Culture, JIT

c. Predictors in the Model: (Constant), Culture, JIT

d. Predictors in the Model: (Constant), Culture

e. Predictor: (constant)

## Appendix F: SPSS Output of Backward-Elimination Multi-Regression Including Outliers

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | C-AVG, S-AVG, J-AVG, Q-AVG[b] | . | Enter |
| 2 | . | C-AVG | Backward (criterion: Probability of F-to-remove >= .100). |
| 3 | . | S-AVG | Backward (criterion: Probability of F-to-remove >= .100). |
| 4 | . | J-AVG | Backward (criterion: Probability of F-to-remove >= .100). |

a. Dependent Variable: TCRsc

b. All requested variables entered.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .124[a] | .015 | .004 | 2.9437435 |
| 2 | .124[b] | .015 | .007 | 2.9394136 |
| 3 | .122[c] | .015 | .009 | 2.9359685 |
| 4 | .103[d] | .011 | .008 | 2.9377685 |

a. Predictors: (Constant), C-AVG, S-AVG, J-AVG, Q-AVG

b. Predictors: (Constant), S-AVG, J-AVG, Q-AVG

c. Predictors: (Constant), J-AVG, Q-AVG

d. Predictors: (Constant), Q-AVG

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 45.618 | 4 | 11.405 | 1.316 | .264[b] |
| | Residual | 2911.650 | 336 | 8.666 | | |
| | Total | 2957.268 | 340 | | | |
| 2 | Regression | 45.537 | 3 | 15.179 | 1.757 | .155[c] |
| | Residual | 2911.731 | 337 | 8.640 | | |
| | Total | 2957.268 | 340 | | | |
| 3 | Regression | 43.739 | 2 | 21.869 | 2.537 | .081[d] |
| | Residual | 2913.530 | 338 | 8.620 | | |
| | Total | 2957.268 | 340 | | | |
| 4 | Regression | 31.534 | 1 | 31.534 | 3.654 | .057[e] |
| | Residual | 2925.734 | 339 | 8.630 | | |
| | Total | 2957.268 | 340 | | | |

a. Dependent Variable: TCRsc

b. Predictors: (Constant), C-AVG, S-AVG, J-AVG, Q-AVG

c. Predictors: (Constant), S-AVG, J-AVG, Q-AVG

d. Predictors: (Constant), J-AVG, Q-AVG

e. Predictors: (Constant), Q-AVG

## Coefficients[a]

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 1.870 | .709 | | 2.637 | .009 |
| | S-AVG | .103 | .235 | .045 | .440 | .660 |
| | Q-AVG | -.516 | .282 | -.233 | -1.827 | .069 |
| | J-AVG | .257 | .259 | .102 | .990 | .323 |
| | C-AVG | .022 | .222 | .010 | .097 | .923 |
| 2 | (Constant) | 1.874 | .706 | | 2.653 | .008 |
| | S-AVG | .106 | .232 | .046 | .456 | .649 |
| | Q-AVG | -.505 | .259 | -.228 | -1.950 | .052 |
| | J-AVG | .264 | .248 | .105 | 1.064 | .288 |
| 3 | (Constant) | 1.958 | .681 | | 2.874 | .004 |
| | Q-AVG | -.438 | .212 | -.198 | -2.059 | .040 |
| | J-AVG | .288 | .242 | .114 | 1.190 | .235 |
| 4 | (Constant) | 2.364 | .590 | | 4.006 | <.001 |
| | Q-AVG | -.228 | .119 | -.103 | -1.912 | .057 |

a. Dependent Variable: TCRsc

## Excluded Variables[a]

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics Tolerance |
|---|---|---|---|---|---|---|
| 2 | C-AVG | .010[b] | .097 | .923 | .005 | .276 |
| 3 | C-AVG | .016[c] | .153 | .879 | .008 | .280 |
| | S-AVG | .046[c] | .456 | .649 | .025 | .289 |
| 4 | C-AVG | .050[d] | .519 | .604 | .028 | .311 |
| | S-AVG | .069[d] | .699 | .485 | .038 | .302 |
| | J-AVG | .114[d] | 1.190 | .235 | .065 | .316 |

a. Dependent Variable: TCRsc

b. Predictors in the Model: (Constant), S-AVG, J-AVG, Q-AVG

c. Predictors in the Model: (Constant), J-AVG, Q-AVG

d. Predictors in the Model: (Constant), Q-AVG