Classifying Lean Production: A Review of Empirical Research

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***Abstract* – Lean production has been studied extensively during the past few decades. Many authors agree that Western production techniques are outdated and that there is a significant shift towards the "Lean" production philosophy. The purpose of this paper is to review and classify the lean production empirical research, identify well-traveled paths, and offer suggestions for future research. This study provides an up-to-date, review and classification of lean production empirical research. Articles were collected from the premier refereed journals in the fields of Supply Chain and Operations Management. A classification model of the articles, based on four fundamental lean production principles, is presented in the paper. A majority of the articles included in this review concentrate on an operations or elimination of waste element. Future research paths, including "Sustainable" lean production are discussed.**

***Keywords* –** Lean Production, Literature Review, Empirical Research, Classification Model, Just-in-time

1. Introduction

The Lean Production (LP) and Just-in-time (JIT) philosophies have attracted a considerable amount of attention in the literature during the past twenty years. Due to the widespread success of the Toyota's system of production (the basis for lean systems) in the automotive industry, lean production has morphed into one of the leading research tracks in the field of Operations Management (OM). Lean production and JIT methods are standard practice in the manufacturing industry, and they are rapidly expanding to the public and service sectors. Researchers and practitioners have studied the topic from the implementation stage to post-adoption success utilizing many different methods including case studies, simulations and mathematical models, conceptual models, and empirical studies. This research seeks to review the empirical articles published during the past few decades in the premier OM journals. The primary objective is to categorize the articles based on their content, highlight some common themes, and to provide some direction for future research. The terms "lean production" and "just-in-time production" are often intertwined in the literature, hence the inclusive nature of this literature review.

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It is imperative to understand the origin and history of JIT and lean production before the terms can be defined. JIT production is recognized as one of the key facets of the Toyota Production System (TPS) that was developed by Taiichi Ohno with Toyota Motor Company from the late 1930s until his book, *Toyota Production System*, was published in 1978 (in Japanese). The TPS seeks to improve upon the Ford Production System and mass production philosophy that was developed by Henry Ford. The goal of the TPS is efficiency and productivity improvement based on respect for people, quality control, equipment maintenance, and the JIT production philosophy [1]. According to Ohno, the underlying point of JIT is production quantity control by only producing the type of units needed, at the time they are needed, and only producing the quantity that is needed. Essentially, JIT attempts to reduce cost by eliminating waste through inventory minimization, set-up and change-over time reductions, and reliable equipment, just to name a few. JIT also strives to continuously improve the business by integrating suppliers, empowering the employees of the company, and quality control/improvement. Ohno later translated his book to English in 1988 as *Toyota Production System: Beyond Large-Scale Production*. This pivotal book subsequently opened the door to an abundant amount of JIT research and a widespread shift in manufacturing philosophy in the Western World.

One of the early publications on the Toyota Production System and implementation of Just-in-time principles came from [2]. Ref. [2] introduced the Toyota Production System and Kanban System with specific discussions on JIT and the respect for people elements. Ref. [3] followed by coining the term "lean production" to describe the TPS and was one of the first to demonstrate that lean production methods can lead to enhanced operational performance. Finally, *The Machine that Changed the World* [4] revolutionized the lean production landscape based on its in-depth discussion and organization of lean production. This book was the product of data collected during the International Motor Vehicle Program (IMVP) research project conducted at The Massachusetts Institute of Technology. The IMVP was sponsored by nearly every automotive manufacturer in the world and lasted from 1985-1990. The primary component of the IMVP consisted of a large-scale data collection effort labeled the International Assembly Plant Study. A massive database was created with the data collected during the study and served as the basis for many lean production research projects to come.

Ref. [5] addressed the confusion associated with JIT, lean production and other forms of lean implementation

by offering a conceptual definition of lean production. They conclude that lean production is not a singular concept; rather it is the combination of all waste elimination and continuous improvement components. In essence, JIT production is encompassed in lean production among many other principles. Both systems share a common goal of increased performance through the elimination of waste, and therefore, it is easily understood how the terms can be misunderstood and used inter-changeably in the literature. For the purpose of this research, lean production terminology will be used throughout the rest of the paper with the understanding that just-in-time principles are included in lean production.

Lean production has been empirically researched from a multitude of angles. The primary argument by academics is that implementation of lean production will positively affect performance and lead to competitive advantage [3], [6], [7], [8], [9]. Another viewpoint that has been investigated is the impact of lean production on industries in countries other than the United States [10], [11], [12], [13], [14]. Finally, lean production has been examined based on simultaneous implementation of JIT and TQM [15], [16], JIT infrastructure and practice from a managerial perspective [17], [18], [19], and JIT implementation progress [20], [21], [22].

To date, there have been a few literature reviews on JIT philosophy and implementation [23], [24], [25]. All of the reviews are at least twenty years old and focus primarily on just-in-time implementation with a very limited section about the empirical research. There have been very few comprehensive literature reviews of the extant lean literature, with none of them concentrating on lean production empirical research. Ref. [5] offers a substantial sample of the historical lean production literature, but their study is structured towards defining lean production without focusing on empirical lean production research. Consequently, there is adequate need for a current review of lean production empirical research. The primary contribution of this research is the summary of the issues that have been addressed in the literature and the guidance down the roads least traveled. This review could be used by researchers to determine areas of lean production that require additional research and by practitioners that are looking for research that has been published on certain concepts or topics of lean production.

The remainder of this paper is constructed as follows. The next sections provides a detailed literature review by identifying the lean production research trends as well as classifying research based on the common themes of lean production retrieved from the literature. Then, a description of the research method and article collection process, including the targeted journals is presented. Next, the avenues for further research are discussed. Finally, the paper concludes with a summary of the key findings and some limitations to the study.

2. Literature Review

Research has shown that lean production implementation has opened the door to tremendous opportunities for improvement in operational performance metrics [10]. Due to the vast array of literature available and the inconsistencies present within the topic, now would be a good time to draw a line in the sand and determine what has already been explored or is already known, and what areas require further research. The best method that can be employed to answer this question is a comprehensive literature review of the subject. There have been hundreds of articles published in the past few decades that conceptualize, discuss, debate, and define various aspects of the lean philosophy. The purpose of this study is not to conduct an exhaustive review of all lean research. In this study, lean production empirical research is examined including the impact of those production philosophies on organizations throughout the world. Therefore, this review concentrates strictly on the lean production dimension of the lean philosophy, which has been highlighted by many authors as one of the critical and most widely adopted dimension of lean. Table 1 presents a description of the articles selected for the review, in order of appearance.

Table 1. Literature Reviewed

Ref.	Research Description
[5]	Examined the confusion surrounding lean production empirically via a field survey and develops a lean production measurement model and conceptual definition
[7]	Utilized financial/accounting data concerning measures of organizational performance to examine the impact of just-in-time production on performance with empirical support from a field survey
[8]	Archival study that measures the impact of lean production on the firms that have adopted the philosophy
[9]	Archival/Field study that investigates the effects of just-in-time, total quality management, total preventive maintenance, and human resource management on operational performance
[10]	Examines the relationship between JIT manufacturing and four measures of performance (productivity, quality, lead time, and customer service) in Mexico based on a field survey
[11]	Archival study that examines the role and significance of lean production within the context of the industrial and economic environment in Japan
[12]	Archival study that investigates the linkage between work-in-process inventory and manufacturing productivity
[13]	Field survey to identify problems that Egyptian firms face when implementing JIT, the benefits of JIT, and to explore the relationship between human modification efforts to be undertaken prior to JIT implementation and JIT success
[14]	Investigates the degree of use of some of the most representative lean production practices, their relationship with plant size and their effect on the performance of the company via a field survey
[15]	Utilizing a field survey, the authors developed a set of guidelines and practical considerations that companies can use for implementation of either program.

[16]	Explores the workforce practices and synergistic benefits of joint JIT-TQM implementation by comparing four groups of companies based on their implementation status of JIT and TQM based on data collected from a field survey
[17]	Field survey that examines companies that claim to be lean and their investment in training and development of the workforce with the assumption that "lean" companies will invest more than non-lean companies.
[18]	Analyzed the relationship between JIT and five infrastructure practices: quality management, work force management, manufacturing strategy, organizational characteristics, and product design with a field survey
[19]	Measured the differences in variable cost functions between JIT users and non-JIT users to support the idea that JIT environments are more productive than non-JIT based on the results of a field survey.
[20]	Analyzes JIT implementation in US manufacturing firms with empirical support from a field survey
[21]	Investigates the organizational design configurations of a broad base of firms that are in-process of implementing and developing the JIT philosophy with support from a field survey
[22]	Investigates the differences among companies at various stages of just-in-time implementation based on internal and external factors via field survey method
[26]	Conceptual study that develops a framework for effective JIT implementation with empirical support from a field survey
[27]	Examined the nature of interactions between manufacturing subsystems and the factors leading to the success of JIT utilizing a field survey
[28]	Investigates the interactive effects of successive incremental improvement techniques (TQM & JIT) and how technological innovations were managed in conjunction with the implementation of TQM or JIT. A field study method was used with manufacturing performance as the dependent variable.
[29]	Examines JIT implementation in the public sector, specifically the relationships between organizational modification efforts prior to JIT implementation, problems encountered during imp. and JIT success with a field survey
[30]	Utilizing a field survey, the authors developed and tested an integrated checklist to assess manufacturing changes towards lean production
[31]	Empirically examines via a field survey the connection between lean production and various aspects of the logistics system (compares lean and non-lean suppliers)
[32]	Field survey that addresses the effect of lean production implementation on worker stress
[33]	Cross-sectional and longitudinal study that measures the degree of JIT implementation in US manufacturing companies and how it affect financial performance by conducting a field survey
[34]	Investigates lean manufacturing paradigms and performance capabilities in global manufacturing firms with support from a field survey
[35]	The authors developed and tested a model to determine whether the use of JIT purchasing reduces logistics costs for both suppliers and buyers using a field survey and confirmatory factor analysis
[36]	Archival study that simultaneously examines the practices of JIT, TQM, and TPM and their effect on performance
[37]	Measures the impact of JIT on accounting measures of performance based on JIT implementation dates and archival data from US manufacturing firms
[38]	Investigates the benefits that firms have experienced through JIT adoption and whether a more comprehensive implementation is worthwhile utilizing field survey responses from JIT practicing firms
[39]	Exploration of post lean implementation production costs using evidence from the Lockhead Martin F-22 program.
[40]	An inventory leanness measure is developed to study if firms can become too lean.
[41]	Investigation of lean production systems at an Indian software services firm, specifically focusing on knowledge work (task uncertainty, process invisibility, and architectural ambiguity).
[42]	Modeling study that explores the informational and incentive rationales for reduced inventories through JIT with empirical evidence from a field survey
[43]	Investigates the JIT implementation differences between small and large U.S. manufacturers utilizing a field survey
[44]	Examines the effect of product variety on total labor productivity and consumer-perceived product quality using archival data from the International Motor Vehicle Program at MIT
[45]	Employs a field survey to explore the relative importance of several JIT-based independent variables to the total level of supplier-linked inventory in a JIT environment
[46]	Compares stock turnover data on Japanese manufacturers and Western manufacturers from 1975-1988 to determine if the performance gap is narrowing
[47]	Conducted an archival analysis of the environmental performance of 17,499 U.S. manufacturing establishments from 1991-1996 to study the link between lean production and environmental performance
[48]	Examined the relationship between lean manufacturing practices and environmental performance as measured in terms of air emissions and resource use
[49]	Sample of tier one auto. Suppliers to investigate impact of supply chain cooperation on lean production adoption
[50]	Hybrid model of Socio-Technical Systems and Lean Production is developed using supplier data from Swedish manufacturing industry
[51]	Tests the complementarity effects on operational performance of JIT and TQM.

2.1. Research Trends

As a first step towards classification of the literature, it was important to understand the history of lean production and path of research during the last twenty years. Two broad categories of lean production research emerged from the literature based on the status or degree in which the lean production / just-in-time philosophy has or has not been implemented and the concentration of the article. The first category deals with LP implementation and the

second category is concerned with LP practice. Lean production implementation articles typically discuss the importance of lean production [20], identify hurdles and obstacles that companies face during implementation [13], and offer conceptual frameworks to assist managers with the implementation process [26]. Lean production practice articles primarily focus on performance and competitive advantage achieved by ongoing continuous improvement [8], [9], [10]. Empirical research is dominated by comparisons of companies that have implemented lean production with those that have not and the realized benefits of a lean production system [17], [18], [34].

Lean production research was mostly focused on implementation during the late 1980s and early 1990s. This was followed by a cyclic pattern of research from the mid-1990s through the mid-2000s and wrapped up with a distinct shift in research concentration to lean production practice during the past several years.

2.2. Classification of Research

Lean production implementation and practice research centers on the benefits to organizational performance with respect to four key principles of the lean production philosophy, which include: respect for people, elimination of waste, supplier involvement, and quality control [1], [4]. These four principles are the foundation of lean production and have been covered extensively in the literature. Each principle will be described in further detail in the coming sections.

In order to effectively classify the selected articles for review, a generic framework is created based on the two categories of research and four fundamental principles of lean production and just-in-time. Figure 1 presents the "SPOT" (Suppliers, People, Operations, Total Quality Management) model that will be used for the classification. This model was created based on a broad view of the four key principles of lean production discussed above. It was necessary to approach the classification from a broader perspective than [1] and [4] presented due to the complexity of the material contained in a wide range of publications. Each article will be classified under either LP Implementation or LP Practice and at least one of the four principles based on the concentration of the article. There are a few of the articles that discuss one or more of the principles, therefore some overlap will occur during the classification process. In other words, the four elements of the lean production "SPOT" model are not necessarily mutually exclusive. The classification strategy is subjective and open for interpretation, but every effort was made to effectively classify the articles in the manner that is most appropriate based on my interpretation of the literature. The correlation between the elements proposed in the framework here and the four key principles of lean production should be apparent (i.e. respect for people = People, elimination of waste = Operations, etc.), except that the elements proposed here stem from an all-inclusive, wide-angle perspective. One could argue that elimination of waste in terms of labor could be categorized as People or Operations, which is true, but in the context of this research, the author considers all forms of waste that could fall under another category (e.g. excessive labor, supply chain waste) as operational waste.

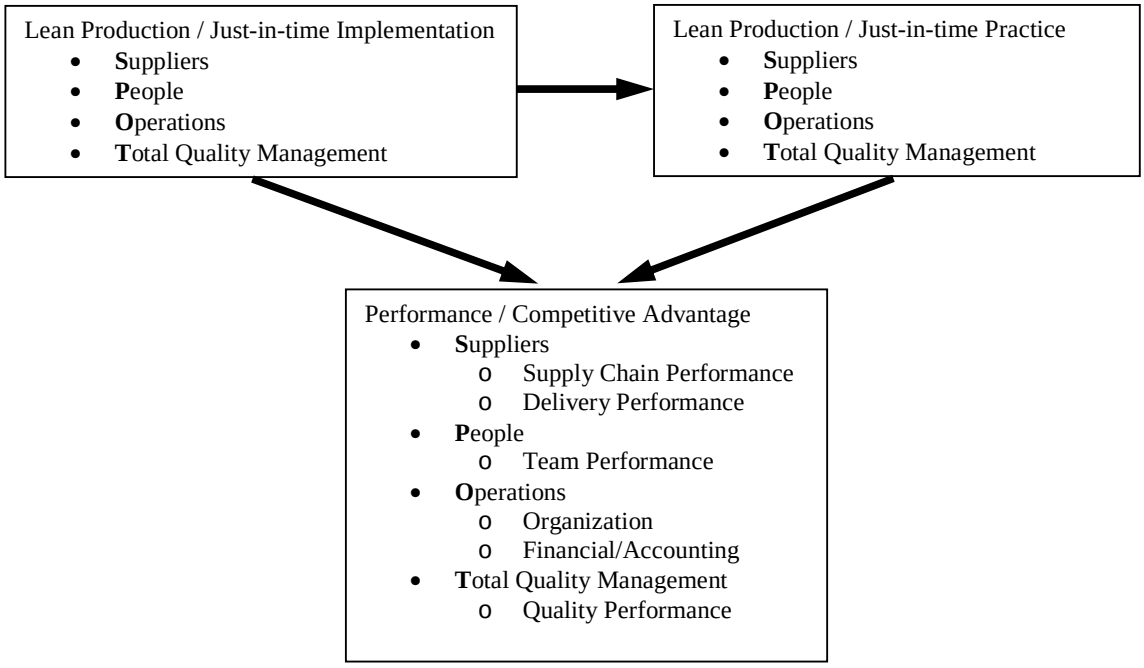

Figure 1. Classification model for lean production empirical research

Table 2 presents the classification of the articles included in the review. The primary objective of this table is to identify the well-traveled paths of research utilizing the four elements of lean production and the associated weight of each based on the total number of articles that concentrate on a particular aspect of an element. This table will also be used as the template for the discussion on each element and the common variables that have surfaced from the research. As you can see in the table, the majority of the articles have focused on an operations related aspect such as inventory management or manufacturing strategy, and they have accounted for nearly 50% of the entire population of articles with an apparent trend in lean production practice research. Supplier related research is the minority in this sample and only accounts for about 10% of all articles published. The next few sections will provide a detailed discussion on each of the four lean production principles and offer insights from the various authors included in the review.

Table 2. Classification of lean production articles

Reference	Lean Production Implementation				Lean Production Practice			
	Suppliers	People	Operations	TQM	Suppliers	People	Operations	TQM
[5]							*	
[7]							*	
[8]							*	
[9]						*	*	*
[10]							*	*
[11]							*	
[12]							*	
[13]			*					
[14]							*	*
[15]			*	*				
[16]			*	*				
[17]						*		
[18]		*	*	*				
[19]						*		
[20]		*	*	*				
[21]			*					
[22]	*	*	*					
[26]	*	*	*	*				
[27]						*	*	
[28]			*	*				
[29]		*						
[30]	*	*	*					
[31]					*			
[32]		*						
[33]					*		*	
[34]							*	
[35]					*			
[36]							*	*
[37]							*	
[38]		*	*	*				
[39]							*	
[40]							*	
[41]	*		*					
[42]							*	
[43]		*						
[44]						*	*	
[45]	*							
[46]							*	
[47]							*	
[48]							*	
[49]	*							
[50]						*	*	*

[51]							*	*

2.2.1 Suppliers

Articles classified under the "Suppliers" element have received scant attention in the literature and typically focus on supply chain efficiencies, supplier integration, and delivery performance. Many authors agree with the point that supplier participation and integration is one of the key aspects of lean production implementation and practice.

Ref. [26] conducted a survey to determine the impact of supplier cooperation in terms of communication and information exchange, correctly supplied materials, and the timing of the shipments from the suppliers. They conclude that all three are significant factors to the success of JIT and ongoing supplier relationship management should be a priority for JIT implementation and practice.

Some authors argue that suppliers should be within close proximity of the firm to help reduce delivery lead-time. Ref. [22] studied five supplier related factors that are considered to be important for JIT implementation. They also investigated the number of suppliers for the major of components, the relationship between the firm and supplier for quality improvement, and supplier evaluations on reliability, product flexibility, and quality. The authors found, via a field survey at JIT implementing companies, that supplier proximity, the number of suppliers for the major parts, and the supplier evaluations were not significant factors for JIT implementation, which contradicts traditional JIT philosophy. The authors did find support for the notion that quality improvement cooperation with the suppliers does have a positive impact on JIT implementation.

Ref. [45] conducted an exploratory study on supplier inventory reduction in the form of supplier finished goods, in-transit inventory, and customer (manufacturer) raw material, with independent variables such as lot sizes, lead times, schedule stability, and product quality. Chapman contends that small lot sizes and reduced lead times will lead to substantial cost savings from inventory reductions. He stressed that JIT implementation in the supply chain should begin "by providing supplier education and communication of intentions to prevent counterproductive supplier responses" ([45], p. 2006). There were a couple of papers that concentrate on the performance and competitive advantage gained by lean suppliers [30], [31]. Ref. [31] concluded that lean manufacturing techniques implemented by the supplier can lead to competitive advantage through advancements in production systems, distribution systems, communications, transportation systems, relationships, and delivery performance.

As you can see from the entries above, most articles focus on the benefits of lean production/just-in-time realized by the buyer or manufacturer. Very few publications discuss the benefits, or lack thereof, to the supplier. One of the most interesting discoveries in the literature comes from ref. [35]. They agree with authors of other articles regarding the concept that manufacturers can potentially shift their inventory cost to the suppliers through implementation of JIT [52], [53], [54]. This was one of only a few articles that shed negative light on lean production and JIT implementation.

2.2.2 People

Another element of lean production titled "People" stems from the original JIT philosophy "respect for people" but adheres to a more all-inclusive, macro view of the literature. Articles in this category typically discuss managerial commitment to lean production implementation, management strategies, workforce stress, employee empowerment, and implementation in the public sector.

Ref. [17] conducted a survey in the metalworking industry to examine the relationship between company commitment to lean production and the actions of managers to develop their workforce. He claims that effective leadership, workforce training, worker empowerment, and the use of small groups for problem solving are critical aspects for lean production and lead to increased productivity. Ref. [20] sought to determine critical factors for successful JIT implementation. They discovered that commitment from top management was one of the most critical factors for successful JIT implementation. They conclude that JIT efforts are more likely to be successful when a long-term view is taken instead of a short-term, profit-oriented perspective.

Some papers investigated management strategies and their impact on JIT implementation and performance [19], [30]. It could be argued that management strategy is the most important issue for on-going lean production success. Management strategy can incorporate all of the other "People" related philosophies including training, employee involvement, workforce empowerment, etc. Ref. [19] determined that firms that claim to be following JIT management strategies are more profitable, have lower production costs, and effectively utilize their capacity. The authors suggest that managers attempting to implement JIT should focus on process and product quality improvements, preventative maintenance programs, and speedy parts delivery.

One viewpoint that is scarce in the literature is the effect of lean production on worker job stress. Ref. [32] issued a survey to workers at 21 sites in four United Kingdom industries. Based on 1,391 responses, they determined that lean production itself is not necessarily stressful, but most of the work related stress comes from management decisions regarding the design and operation of lean production systems. Their finding that lean production itself is not stressful supports the notion that JIT and lean production should be applied to the organization as a whole, but it should not be applied to people.

Lean production and JIT in the public sector is another area that is not represented well in the literature. Ref. [29] examined this topic with the intent to understand the problems encountered during implementation and factors that led to success of the systems. They surveyed 86 public sector organizations and discovered that the public sector is very similar to its private counterparts in that

operational efficiency, service quality, and organizational effectiveness can be improved by implementing JIT. They call for future research in the area of lean production and JIT implementation design.

2.2.3 Operations

A majority of articles included in this literature review covered a topic in the operations element of lean production. Operations related research focuses on the elimination of waste at all levels of the enterprise, particularly inventory, lot-size, and set-up times. Operations papers also discuss manufacturing flexibility, complexity, push/pull strategy, and total predictive maintenance (TPM).

Ref. [21] studied the implementation of JIT in the USA, especially in small or medium-sized firms. Based on a survey of plants that are in-process of JIT implementation, he found that many are reaping the benefits of inventory reduction, lot-size reductions, and quick set-up. He determined that large firms have begun the process sooner and have taken more steps towards implementation than small to medium-sized firms.

Ref. [9] explored lean production principles and the effects of plant size, plant age, and unionization status on successful implementation of 22 key manufacturing practices. Utilizing data from IndustryWeek's Census of Manufacturers, they found evidence to support the idea that large plants will have a negative impact on lean production implementation. However, they did not find much support for the effect of plant age and unionization status on lean production implementation.

Productivity received a great deal of attention in the articles selected for the review. Ref. [45] studied the effect of product variety on manufacturing performance, namely total labor productivity. Complexity and product variety refer to the act of building/assembling the same components with a different set of parts/options in the same space or on the same line. An example would be the scenario of assembling two personal computers in the same space with entirely the same components except two different sizes of memory capacity. Ref. [44] determined that parts complexity has a significant negative impact on productivity but model complexity does not have as significant of an effect on productivity. Ref. [12] investigated inventory reduction and productivity growth in the context of the Japanese automotive industry. They sought out to determine and empirically justify the link between work-in-process inventory reduction and manufacturing productivity. They collected archival data for 52 Japanese companies and found that on average a 10% reduction in inventory leads to a 1% gain in labor productivity. According to the authors, inventory reduction spurred other process improvements such as set-up time reduction and statistical process control and ultimately led to the productivity gains. This is based on the notion that inventory reduction will uncover process inefficiencies and other manufacturing problems due to the lack of an inventory buffer. Ref. [5] conclude that firms can achieve a high level of equipment availability and increased productivity through a routine predictive and preventative maintenance schedule.

2.2.4 Total Quality Management

Total Quality Management articles are generally concerned with joint implementation of JIT and TQM principles. Some authors investigate the relationship between TQM and JIT, while other focus on TQM and continuous improvement as one aspect of the larger lean production and JIT picture. Similar to supplier related papers, TQM research is underrepresented in the literature review.

Ref. [16] conducted a survey in the US computer an electronic industry to determine the benefits of joint implementation of JIT and TQM. The questionnaire was sent to companies with no JIT or TQM implementation and to companies that are either in the implementation phase or are actively practicing the disciplines. Responses from 379 participating firms were compiled and analyzed to support the conclusion that companies that were implementing both programs were superior in many performance measures than those companies that did not implement either program. Ref. [36] demonstrate that joint implementation of JIT and TQM along with TPM led to increased manufacturing performance due to the communal nature of the three programs. Ref. [15] contradict the other authors with their deduction that most manufacturers can benefit from selective JIT implementation without putting TQM and JIT into practice simultaneously.

3. Methodology

This study utilizes secondary data by selecting articles for review that have been published in the premier Operations Management journals during the past few decades. The premier journals included in the search are: *Management Science, Operations Research (OR), Journal of Operations Management (JOM), International Journal of Production Research (IJPR), International Journal of Operations and Production Management (IJOPM),* and *Production and Operations Management (POM).* The premier operations management journals were selected based on the ranking of management science and operations management journals from the Australian Business Deans Council 2013 Journal Quality List [55]. One distinct advantage of the selection process used in this study is the limited focus. Limiting the articles selected to those that have been published in the premier operations management journals provides confidence that the article is of the highest quality due to the rigorous review process and high publishing standards in the premier journals.

A comprehensive search was conducted utilizing Google Scholar as well as the online database systems that contain full-text articles from the journals listed above. The reference sections of the identified papers were also examined to determine if any papers were omitted from the initial search. In total, 43 articles were collected from the search process that are included in the review. Even though 43 articles is not an exhaustive amount of research,

it shall provide adequate definition of the well-traveled paths of lean production empirical research.

4. Discussion/Results

Lean production and just-in-time have been researched from nearly every angle during the past twenty years. Even with the abundance of research, there are still areas that require additional investigation. Continuing with the "SPOT" classification model, an "S" could be added to the end of the model to form a new model of research with a "Sustainable" component. There are many articles available that discuss one or more of the four elements of lean production (Suppliers, People, Operations, Total Quality Management) and the associated benefits of implementation and practice. What does it take to sustain those benefits and the competitive advantage that is gained from lean production implementation and/or practice? What is required to sustain long term competitiveness of the firm? Is it possible to reach a point of no return from lean production practice and implementation, as suggested by [41]? What about the environment? What are the implications of lean production to the environment and how do we counter the effects to sustain environmental longevity? Does "lean" and "green" align, or is "lean" mean to "green"? These questions and others remain largely unanswered. There are a couple of papers that begin to scratch the surface of the relationship between lean production and the environment [47], [48]. Thus, there is adequate need for further "Sustainable" lean production research from both a "lean sustainment" as well as triple bottom line (sustainability) perspective.

The tables in this paper have revealed other areas of lean production that require additional research. Supplier related articles represented the least populated category of the classification structure therefore there is a need for additional lean supplier and lean supply chain research. This finding could possibly be attributed to the choice of journals in this study. Lean supplier research may be prevalent in supply chain journals such as the *Journal of Supply Chain Management* or the *Journal of Business Logistics*, and others. Field surveys accounted for over 75% of the empirical research in this study, which opens the door for additional archival and experimental research. There was only one piece that discussed lean production in the public sector. Service and Non-Profit agencies are often overlooked when it comes to lean principles due to the perception of intangible benefits. Additional research in the context of lean service and non-profit agencies might highlight some applicable savings from lean implementation and lead to wide-spread adoption of the systems.

Ref. [56] introduced the knowledge chain model as a tool to link knowledge management and competitiveness based on four dimensions: Productivity, Agility, Innovation, and Reputation (PAIR). Since many lean production articles discuss the competitive advantage that can be obtained via lean production implementation, it would be fascinating to study lean production from the perspective of the four dimensions (PAIR) from their model.

Lean production linked to other aspects of the enterprise or in conjunction with other concepts like Six Sigma might lead to interesting conclusions. Lean Six Sigma attempts to combine the fundamental philosophies of "lean", particularly process speed and efficiency, and the quality improvement techniques of Six Sigma. Lean Six Sigma is a data driven approach to process improvement and customer satisfaction through the use of effective teamwork [57]. The above suggestions represent a few ideas for the future lean production research, but they are not intended to be an exhaustive list of all possible future research paths. The vast nature of the lean production and JIT philosophies inherently dictates research in many forms and directions.

There are several limitations to this study. First, the literature review was limited to only the premier and highly ranked operations management journals. It is almost certain that many insightful and groundbreaking articles have been published in journals that were not included in this search and could lend valuable information to this study. The review was limited to only empirical research in lean production and just-in-time. Again, this approach excludes many conceptual pieces and a host of analytical/simulation work that could have greatly influenced this review. Another issue with this approach is the fact that only 43 articles were retrieved from the search process. This could partially be attributed to the nature and focus of the journals included in the review (i.e. Management Science maintains a quantitative focus and publishes a large number of modeling studies). Forty-three papers can provide a snap-shot of the current research landscape but may be considered too few to establish long-term themes.

As can be witnessed by the interchanging use of lean production and JIT in this paper, the topic is very hard to define and overlaps occur in the literature. There may have been some articles that were excluded from the review on the basis that different terminology is used to describe similar programs. Ref. [5] offered an integrated definition of lean production to help dispel the confusion in the literature.

Finally, one could argue and most likely support an alternative to the classification scheme employed for the literature analysis. There are many different dimensions of lean production and just-in-time, but the author chose to expand upon the four fundamental themes of lean production mentioned throughout the papers and offer a more macro view of the supplier participation, respect for people, elimination of waste, and quality management philosophies.

5. Conclusion

This paper put forth an effort to classify the empirical research on lean production. In the process, the review revealed two general categories of lean production literature: lean production implementation and lean production practice. A "SPOT" classification model is developed that is an extension of four fundamental principles of lean production in terms of suppliers, people, operations, and total quality management. Supplier related articles focus on supplier integration in the lean production system, whereas people associated papers

discuss managerial commitment/decisions and workforce empowerment. The element of operations was the most populated group and typically concentrate on elimination of waste at all levels of the enterprise. Finally, total quality management articles are concerned with joint implementation of JIT and TQM principles and ongoing quality improvement.

There are many different available paths for future research. One aspect that has not been extensively covered in the literature is the emerging global phenomenon of sustainability. What role does sustainability play in the context of lean production is an interesting question that remains unanswered. Other directions that require further investigation include lean production in service and non-profit organizations, additional supplier and supply chain research, and research utilizing empirical methods other than a field survey.

Based on the hundreds of research papers that investigate lean production and just-in-time systems, there is a rich history of lean production research that has no apparent end in sight. The literature review presented here and the questions that remain unanswered stimulates additional research in the fruitful lean production arena.

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