Publication metadata:

Title: The mediating effect of lean management on the relationship between flexibility implementation and operational metrics in US automotive manufacturing plants

Author(s): Raed El-Khalil

Journal: Journal of Manufacturing Technology Management

DOI: https://doi.org/10.1108/JMTM-04-2018-0108

The mediating effect of lean management on the relationship between flexibility implementation and operational metrics in U.S automotive manufacturing plants

Raed EL-Khalil

Department of Information Technology and Operations Management,

Lebanese American University, Beirut, Lebanon

Abstract

Purpose – The purpose of this paper is to identify the mediating effect of lean management (LM) dimensions on the relationship between flexible manufacturing systems (FMS) dimensions and operational performance metrics.
Design/methodology/approach – A survey questionnaire was developed based on previous literature and interviews conducted at the automotive facilities visited that identified 28 lean dimensions, 15 flexibility dimensions, and 8 operational performance metrics. The survey was presented to 175 North American automotive manufacturing managers through interviews conducted at 64 automotive facilities. A total of 164 usable responses were studied.
Findings – Lean and FMS are multi-dimensional philosophies, the results demonstrate that the automotive industry in North America have implemented many dimensions of both philosophies. Each dimensions is categorized based specific organizational metrics. The 64 facilities studied use common dimensions identified by this study for lean and flexibility. Data analysis indicate direct link between lean, flexibility and operational metrics. It shows that lean manufacturing plays a critical role in improving the impact of flexibility on performance metrics. The results also indicates that specific lean and FMS dimensions or categories have higher significant role than others in the relationship between LM, FMS, and operational performance metrics.
Research limitation – Since the sample size only considered automotive manufacturing facilities, the results need to be considered with caution.
Originality/value – This research empirically develops a framework linking FMS and LM to operational performance metrics. This research address an area within which little consensus on the relationship between LM, FMS and their impact on operational performance metrics. The study is unique because the depth and breadth of LM, FMS, and operational dimensions is far more than previous literature. In addition, this research highlights the LM and FMS practices which managers should focus on when attempting to improve operational performance metrics at their facility.

Keywords: Lean Manufacturing, Flexible Manufacturing Systems, Operational Performance Metrics, Automotive Industry, Manufacturing Industry

1- Introduction

Today's manufacturing companies are far more advanced and sophisticated than ever before. Leading countries in the development of cutting-edge technologies around the world, such as United States and Germany, are now experiencing a rebirth in the global market. Countries' investments in innovation, technology, and advantaged manufacturing have created a new battlefield for competitiveness. The 2016 Global Manufacturing Competitiveness report (Deloitte, 2016) identified 12 major drivers of manufacturing competitiveness, namely talent, cost competitiveness, workforce productivity, supplier network, legal and regulatory system, education infrastructure, physical infrastructure, economic and financial system, energy policy, local market attractiveness, and healthcare system. The report explained that success in improving the 12 drivers relies heavily on the ability of manufacturers to adopt new manufacturing philosophies, mainly Lean Manufacturing (LM) and Flexible Manufacturing Systems (FMS). IndustryWeek (2016), reported on the future of manufacturing for 2020 and beyond, investigating technology and management priorities enabling "Global competitiveness in the years ahead" and focusing particularly on growth and challenges facing US manufacturing companies. The report divided manufacturing companies into three main categories based on annual sales: small ($100 million or less), medium ($100–$999 million), and large ($1 billion plus) companies (Barbier, 2017). One of the main conclusions of the report is that the survival and success of manufacturing companies of any size in the US depends heavily on successful implementation of LM and FMS philosophies.

LM and FMS philosophies are both designed to improve manufacturing process performance (Shah & Ward, 2007; Goldsby et al., 2006). The two philosophies differ in their approach toward achieving improvement. LM is a systematic process focused on identifying and elimination waste, such that successful implementation will improve quality, reduce lead time, and cut costs (Boyle & Scherrer-Rathje, 2008 Agarwal et al., 2006). On the other hand, FMS focuses on implementing certain dimensions, such as labor, machine, operations, and material handling flexibilities, which allows the manufacturing system to absorb problems with little or no impact to overall system performance or throughput (Hazen et al., 2017; Gunasekaran et al., 2008; Hormozi, 2001;

Harrison, 1997). There is considerable confusion and little consensus regarding the relationship between the concepts of lean and flexibility in the literature. According to Purvis et al. (2014) and Krishnamurthy and Yauch (2007), previous work has divided the relationship between LM and FMS into three general positions, as illustrated in Table 1: mutually exclusive (cannot exist together), mutually supportive, and LM as a precursor to FMS. According to Boyle and Scherrer-Rathje (2009), flexibility will have a negative impact on lean; for example, back-up machinery increases the incidence of idle machinery from a lean perspective, but improves flexibility. Narasimhan et al. (2006); Jin-Hai et al. (2003) and Naylor et al. (1999) concluded that lean will have a positive impact on flexibility since lean lays the foundation for improving cost, quality, and lead time.

Driven by the lack of consensus regarding the relationship between lean and flexibility, and their impact on operational performance metrics, this paper examines the mediating effect of LM on the relationship between FMS dimensions and operational performance metrics. Data was collected through a survey provided to senior managers at automotive and powertrain manufacturing facilities in US manufacturing companies.

Table 1. The three general positions on the relationship between lean and flexibility

Author name and year	Mutually Exclusive	Mutually Supportive	Lean is Precursor to FMS	Lean/FMS impact performance metrics
Slack (1983)		x		x
Slack (1987)		x		x
Goldman and Nagel (1993)			x	
Kidd (1994)	x			x
Upton (1994)			x	
Flynn et. al (1995)			x	x
Womack and Jones (1996)		x	x	x
Harrison (1997)		x	x	
Gunasekaran (1999)		x		x
Gunasekaran (1999a)		x	x	x
Gunasekaran (1999b)		x	x	x
Katayama and Bennett (1999)		x		
Naylor et. al (1999)		x		x
Samson and Terziovski (1999)			x	x
Christopher and Towill (2001)		x	x	x
Cua et. al. (2001)			x	
Hormozi (2001)			x	x
McCullen and Towill (2001)		x		x
Fullerton and McWatters (2002)		x		
Herer et. al (2002)			x	x
Towill and Christopher (2002)		x	x	
Jin-Hai (2003)			x	x
Shah and Ward (2003)			x	x
Challis et. al. (2005)			x	x
Rahman and Bullock (2005)			x	x
Slack (2005)		x		
Wikner and Rudberg (2005)		x		
Agarwal et. al (2006)			x	x
Da Silveira and Giovani (2006)			x	x
Faisal et. al (2006)		x		
Goldsby et. al (2006)		x	x	x
Narasimhan et. al (2006)			x	x
Taylor (2006)		x		x
Taylor and Wright (2006)			x	x
Vonderembse et. al (2006)		x		x
Krishnamurthy and Yauch (2007)		x	x	x
Matsui (2007)			x	x
Shah and Ward (2007)			x	x
Stevenson and Spring (2007)	x			x
Vazquez-Bustelo et. al (2007)		x	x	x
Zhang and Sharifi (2007)		x		x
Anand and Kodali (2008)		x		x
Gunasekaran et. al (2008)		x	x	x
Fotopoulos and Psomas (2009)			x	x
Soni and Kodali (2009)	x			x
Huang and Li (2010)	x			x
Mackelprang and Nair (2010)			x	x
Perez et. al (2010)		x		x
Rahimnia and Moghadasian (2010)			x	x
Shukla and Wan (2010)	x			x
Jasti and Kodali (2015)		x		x
Riet et. al (2015)		x		x
Theagarajan and Manohar (2015)		x		x
Brusset (2016)			x	x
Hazen et al. (2017)		x		x
Schonberger and Brown (2017)		x	x	x
Yin et al. (2017)			x	x

The remainder of this paper is organized as follows. Section 2 reviews the existing literature on LM and FMS, and their impact on operational performance, and develops the research hypotheses. Section 3 presents the research methodology, measurement scale, validation, and data collection and review process. Section 4 outlines the results, descriptive statistics, SmartPLS output, and analyses. Section 5 presents the discussion and conclusion.

2- Literature review and hypothesis development

LM, also known as the Toyota Production Systems, is a philosophy that utilizes a wide range of dimensions/principles—such as the value stream, standardization of work, and pull system—to eliminate waste, reduce lead time, reduce cost, and improve quality throughout the production process (Bortolotti et al., 2015; Womack & Jones, 1996). FMS, on the other hand utilizes 15 primary dimensions to insure that the manufacturing processes in capable of absorbing problems and or stoppages with minimal or no impact to the overall output of the manufacturing process (Vokurka & O'Leary-Kelly, 2000; Gunasekaran, 1999a; Upton, 1994; Sethi & Sethi, 1990; Slack, 1983).

2.1 Lean Manufacturing and Performance Metrics

Literature has historically looked at LM from a technical or philosophical point of view (Taylor, 2006; Shah & Ward, 2003, 2007; Womack & Jones, 1996; Flynn et al., 1995). Ghosh (2013) divided LM views into three levels:

1- Philosophy: Lean focuses on waste elimination and ensuring the best quality possible throughout the production system. According to this view, 80% of LM is about waste elimination and 20% focuses on the system. This philosophy pertains mainly to the identification and elimination of the seven wastes or *muda*: motion, overproduction, inventory, rework, transportation, over-processing, and waiting (Cacho & Terwiesch, 2009; Cua et al., 2001; Womack & Jones, 1996).
2- Rule-driven system: This level is guided by four rules: (1) identify all activity according to sequence, content, timing, and outcome; (2) eliminate ambiguity from the supplier–customer relationship; (3) ensure every product and service follows a clear and simple pathway; and (4) make improvements through scientific methods and ensure they involve all affected employees (Ghosh, 2013; Shah & Ward 2003; Spear & Bowen, 1999).
3- Groups of tools and techniques: This level is aimed at waste elimination through the implementation of lean dimensions. Authors such as Sajan et al. (2017), Wickramasinghe and Wickramasinghe (2017), Lucato et al. (2014), Ghosh (2013), Karim and Arif-Uz-Zaman (2013), Taj (2008), Shah and Ward (2003, 2007), Taylor and Wright (2006), and Pavnaskar et al. (2003) investigated the application of several lean dimensions, ranging between 12 and 101 lean

dimensions and classifications. Authors such as Bortolotti et al. (2015) classified lean dimensions into four separate categories: total quality management, just-in-time, and total production management, and human resource management. Others, such as Shah and Ward (2007), developed 10 distinct factors that categorize lean tools.

The highest level of abstraction resides in the philosophical view of lean, while the lowest lies in the tools and techniques level, which is widely utilized for LM implementation in Japanese and US industry (Ghosh, 2013). Shah and Ward (2003, 2007) indicated that lean implementation has significantly contributed to the improvement of operational metrics in Japanese and US manufacturing companies. Taj (2008) discovered that China started lean implementation much earlier than the United States and Europe (i.e., since 1977). He discovered that implementation of specific lean dimensions have had a significant positive impact on operational performance metrics in a wide range of manufacturing companies. In his paper regarding lean adoption in the Indian manufacturing industry, Ghosh (2013) identified the impact of certain lean dimensions on operational performance metrics. He also discovered that certain lean dimensions might have a negative influence on specific performance measures. According to Nawanir et al. (2013), previous investigations of lean impact on performance metrics has been limited to a small number of lean dimensions and metrics (e.g., from 5–11 dimensions and 3–5 performance metrics). Lucato et al. (2014) discovered, through research into lean implementation in Indonesian manufacturing firms, that increasing the implementation of lean dimensions improves performance metrics.

Based on the above, our first hypothesis, for which we investigate the impact of 28 lean dimensions grouped under seven categories on eight operational performance metrics, is:

H1. A higher level of LM adoption will lead to higher operational performance metrics.

2.2 FMS and Performance Metrics

Manufacturing flexibility provides a systemic approach to robustness (Wei et al., 2017). It provides manufacturing systems with tools that allow it to handle problems such as downtime with minimal or no impact to the overall system throughput (El-Khalil, 2009).

Purvis et al. (2014), explained that literature has confused agility and flexibility, and indicated that flexibility is the foundation for agility. Naylor et al. (1999) characterized flexibility as a competence that is used at the operational level, while agility encompasses a wider scope at the business level. According to Sethi and Sethi (1990), FMS encompasses various dimensions of flexibility at the manufacturing operational level. Each dimension focuses on a different element of the manufacturing system. The first comprehensive investigation into FMS provided 11 types of flexibility dimensions (machine, material handling, operation, process, routing, product, volume, expansion, program, production, and market) divided into three categories: component, system, and aggregate (Sethi and Sethi, 1990). Narain et al. (2000) added two more FMS dimensions (material and labor), and divided them into three different categories: operational, tactical, and strategic. Later, Vokurka and O'Leary-Kelly (2000) identified added two dimensions (automation and new program). Based on Narain et al. (2000) and Vokurka and O'Leary-Kelly (2000), El-Khalil (2009) identified 15 FMS dimensions and divided them into three categories and three sequence-focused processes, as illustrated in Table 2. Authors such as Wei et al. (2017), Hazen et al. (2017), Oke (2013), Slack (2005, 1987), and Koste et al. (2004) introduced the term "mix flexibility," which combines different flexibility dimensions such as machine, material handling, and operations for objectives including rapid changeover and delivering the product while maintaining cost effectiveness.

Table 2. Flexible Manufacturing System dimensions and categories by focus

	Flexibility Type		Definition
			Necessary Flexibility
Operational (focus)	1	Machine	Refers to the ability of the system to switch operation without requiring major effort
	2	Material Handling	The ability to move different part types efficiently for proper positioning and processing
	3	Product	The ease with which new parts can be added or substituted for the existing parts
	4	Automation	The capability of the automation to perform different operation and or add operation
	5	Labor	The ability to change number of workers, tasks performed by workers, and responsibility
	6	Volume	The ability to be operated profitably at different product overall output levels
	7	Routing	The ability to produce a part by alternative routes
			Sufficient Flexibility
Tactical (focus)	8	Process	Relates to the set of part types that the system can produce without major set-up
	9	Operation	The ability of the part to be produced in different ways with alternative process plans
	10	Program	The ability of the system to run virtually untended for a long enough period
	11	Material	The ease to transporting material to the manufacturing facility, as well as to operation within the facility
			Competitive Flexibility
Strategic (focus)	12	Expansion	The ease with which the capacity and capability can be increased when needed
	13	New Design	The ease by which the system to produce a product with different dimensions shape and or dimension
	14	Production	The universe of part types that the FMS can produce
	15	Market	The ease with which the manufacturing system can adopt to a changing market environment

Several empirical studies have considered the impact of flexibility dimensions on certain operational performance metrics (Wei et al., 2017; Purvis et al., 2014; Oke, 2013; Inman et al., 2011). However, the number of studies on this topic is few, and those that have been conducted are limited in scope (Wei et al., 2017). Driven by this fact, the second hypothesis, which pertains to investigation of the impact of 15 flexibility dimensions grouped under three categories on eight operational performance metrics, is:

H2. A higher level of FMS adoption will lead to higher operational performance metrics.

2.3 LM and FMS

There is little consensus in literature regarding the nature of the relationship between LM and flexibility. Purvis et al. (2014) indicated that there is considerable confusion in regards to the two philosophies (LM and FMS) as to their dependency on one another and their content. Most literature has treated LM and FMS philosophies as systems of dimensions and practices, but have tended to view the two topics in an isolation or in terms of progression (Inman et al., 2011). Organization considering isolation of the two philosophies from each other will face difficulty or inability to follow with FMS implement (Inman et al., 2011; Gunasekaran, 1999a, 1999b; Harrison, 1997).

Inman et al. (2011) stated that there are three different views regarding the relationship between FMS and LM: mutually exclusive, mutually supportive, and lean being the foundation of FMS. Gunasekaran et al. (2008) explained that a clear line can be drawn between the two based on the element that each philosophy focuses on. According to Hazen et al. (2017) and Purvis et al. (2014), FMS focuses on rapid configuration in response to problems but does not emphasize elimination of waste as a prerequisite. Wickramasinghe and Wickramasinghe (2017) stated that in comparison to FMS, LM focused on identification and elimination of non-value-added activity (*muda*) throughout the manufacturing process. Naylor et al. (1999) identified seven different criteria to compare the FMS and lean based on rating importance, namely market knowledge, value stream and supply chain, lead time reduction, eliminate *muda*, rapid configuration, robustness, and smooth demand. They explained that the two main criteria that distinguish FMS from lean are robustness and smooth demand.

Based on the literature review, it is clear that there is little consensus regarding the relationship between LM and FMS. Therefore we propose the following hypothesis:

H3. A higher level of lean adoption will lead to a higher level FMS adoption.

Literature on the topic has agreed that both philosophies are designed to address performance metric improvements (e.g., cost, quality, delivery, and lead time). The nature of the relationship is also impacted by the influence of the two philosophies on each other based on the three different types of relationship outlined previously (see Table 1). As such, we propose:

H4. LM has a moderate effect on the relationship between flexibility implementation and operational metrics.

The hypotheses stated above can be depicted in a conceptual model, as illustrated in Figure 1.

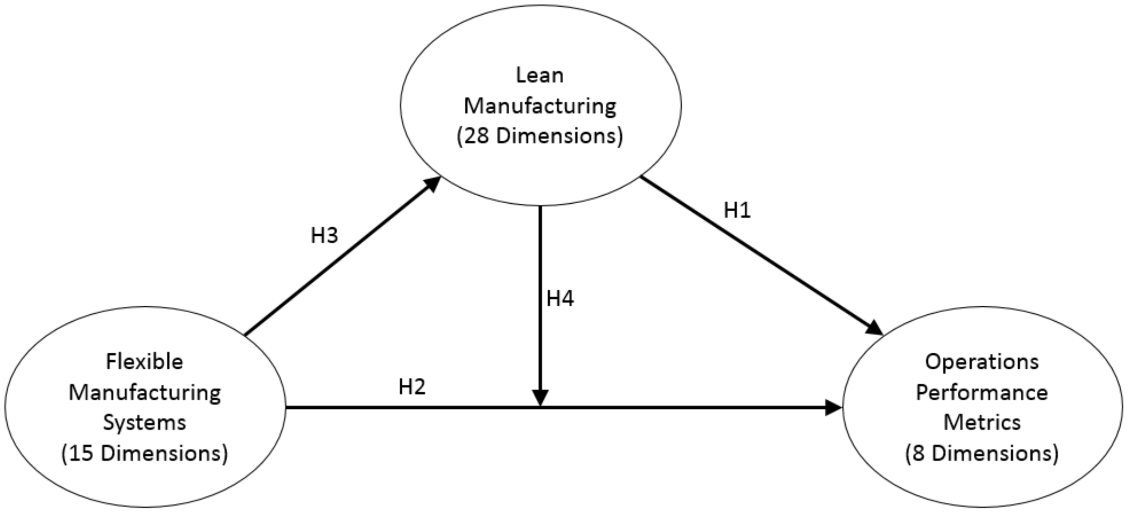

Fig. 1. Conceptual model

3. Methodology

The implementation of LM and FMS in US automotive manufacturing started in the early 21st century. The intent behind the current research is to conduct an empirical study to clarify the relationship between the two philosophies in the automotive industry. This study focuses on domestic original equipment manufacturers —specifically the "Big Three" (Ford, Chrysler, and General Motors). The automotive manufacturing facilities studied are located in North America (United States, Mexico, and Canada). A 58-question survey was developed, and interviews were conducted with senior managers (facility managers, production managers, and engineering managers) at the facilities visited in order to complete it. The survey was carried out between February 2017 and March 2018. In total, 64 automotive facilities were visited, and 175 interviews were conducted, out of which 164 were usable (due to missing data). Facilities visited included assembly (69%) and powertrain (31%). All survey questions were asked to managers during interviews conducted.

3.1 Measurement Scale

The survey questionnaire was developed based on empirical research on LM conducted by Shah and Ward (2003, 2007). Alterations were made to the reference survey in order to suit this research. The final empirical survey included 58 questions related to 28 lean dimensions, 15 flexibility dimensions, and eight operational performance metrics (other questions asked were related to facility demographics). A sample data sheet and the specific dimensions measured are illustrated in Appendix Table A1. The survey developed used a five-point Likert scale for each LM and FMS dimension, with 1 = 0%, or "no implementation of lean or FMS;" 2 = around 25%, or "little implementation;" 3 = around 50%, or "some implementation;" 4 = around 75%, or "extensive implementation;" and 5 = around 100%, or "complete implementation."

Eight questions were developed related to operational performance metrics, again utilizing a five-point Likert scale. These questions were related to quality, customer satisfaction, conversion cost, productivity, lead time, material handling, employee safety or injury reduction, and employee morale. The seven other questions asked in the interviews were related to facility demographics (facility size, number of employees, products produced, facility age, educational level, position, and years of experience). In addition, three unique questions were asked; one related to how managers ranked performance metrics dimensions based on their view of importance, and two related to how they ranked FMS and lean dimensions based on their influence on performance metrics.

3.2 Validation

The survey questionnaire was reviewed by five automotive assembly facility senior production and engineering managers at the Big Three firms. The survey was also reviewed and tested by four academics with theoretical and practical experience in field. The original survey questionnaire was altered based on the feedback received.

3.3 Data Collection and Analysis

Over 77 automotive facilities were visited, out of which 67 were selected for the survey. Of the facilities included in the survey, 69% are considered large, at over $999 million (assembly facilities), and 31% medium, at $100–999 million (PowerTrain). The author is a consultant in the field (lean and flexibility) for the Big Three with over 20 years of experience. All interviews took place at the facilities visited and the managers to be interviewed were identified by the facility managers based on their involvement in the implementation process for LM and LMS. Interviews were scheduled based on the managers' availability. Data was input to Microsoft Excel, and SPSS and SmartPLS software were used for data analysis, which incorporated descriptive statistics, path analysis, partial least squares (PLS) algorithm, and bootstrapping. As the lean dimensions (seven categories) and the flexibility dimensions (three categories or focus groups) constructed in this case are presented as multidimensional, higher-order constructs, the parceling method was utilized to transform them into first-order latent factors (Coffman & MacCallum, 2005).

4. Results

4.1 Measurement Model Assessment

Four tests were utilized to assess the internal consistency and convergent validity of the reflective construct (i.e., Cronbach's α, item loading, composite reliability [CR] and average variance extracted [AVE]), as illustrated in Table 3 and Table A2 (Appendix). In addition, confirmatory factor analysis (CFA) was utilized to determine validity and reliability (Sreedevi & Saranga, 2017; Fornell & Larcker, 1981). All item loadings, CR, and Cronbach's α values surpassed the 0.7 cutoff. The new design and market flexibility dimensions carried standard loadings of 0.684 and 0.692, respectively. When testing their lower bound and upper bound at 95%, we found that new design flexibility ranged from 0.654 to 0.788 and market flexibility ranged from 0.677 to 0.756, which placed both in an acceptable range.

Table 3. Measurement results

Latent Variable	*Category*	Variables Name	Variables Label	Standardized Loadings	Critical Ratio (CR)	Cronbach's α	D.G. rho (CR)	Average Variance Extracted (AVE)
FMS Dimensions	Operational Flexibility	Machine	FMach	0.909	68.273			
		Material Handling	FMH	0.885	60.484			
		Product	FProduct	0.856	46.64			
		Automation	FAutom	0.866	42.982			
		Labor	FLabor	0.898	67.943			
		Volume	FVolume	0.879	49.502			
		Routing	FRout	0.897	72.669			
	Tactical Flexibility	Process	FProc	0.722	8.03	0.935	0.959	0.548
		Operation	FOpera	0.715	8.108			
		Program	FProg	0.721	14.674			
		Delivery /Material	FDlvry	0.775	7.317			
	Strategic Flexibility	Expansion	FExpan	0.796	11.885			
		New Design	FNewD	0.684	7.77			
		Production	FProduction	0.757	21.149			
		Market	FMarket	0.692	16.61			
Lean Dimensions	Information Technology	Autonomation	ITAut	0.832	36.321			
		Enterprise Resource Planning	ITERP	0.829	32.666			
		Material Requirement Planning	ITMRP	0.829	30.769			
		Production planning/Monitoring	ITPPM	0.842	39.782			
	Process Management	Master Planning	LPMMP	0.793	32.917			
		Plan-Do-Check-Act	LPMPDC	0.834	35.381			
		Practical Problem Solving	LPMPPS	0.854	43.887			
		Business Plan Deployment	LPMBP	0.813	34.918			
	Material Handling	Just in Time	MHJIT	0.866	41.473			
		Level Scheduling	MHLS	0.814	33.849			
		Material Line Balancing	MHMLB	0.874	42.517			
		Scheduled shipping	MHTPM	0.878	45.785			
	People Involvement	Job Rotation	PIJR	0.822	29.009			
		Open Communication	PIOC	0.728	19.768	0.983	0.984	0.683
		Qualified People	PIQP	0.902	66.108			
		Small Team Concept	PIST	0.818	28.769			
	Productivity	Line Balance	PLB	0.829	35.68			
		Five S and & 7 waste	P5s7w	0.843	35.976			
		Standardization	PStan	0.773	29.438			
		Lead time Reduction	PLTR	0.808	34.337			
	Process Quality	Direct Run Loss	PQDRL	0.823	36.197			
		Error and Mistake Proofing	PQEampM	0.802	26.713			
		Quality Verification	PQQV	0.839	39.933			
		Total Quality Management	PQTQM	0.869	43.46			
	Process Technology	Decoupling	PTDeC	0.729	18.205			
		Operator Support Devices	PTOSD	0.813	31.305			
		Quick Set-Up	PTQSU	0.82	37.941			
		Total Productive Maintenance	PTTPM	0.844	36.093			
Operational Performance Metrics		Cost Conversion	ConvCos	0.938	104.188			
		Customer Satisfaction	CustSat	0.92	80.654			
		Employee Safety	EmplSafety	0.945	108.703			
		Productivity	Prodvty	0.923	96.927	0.974	0.983	0.848
		Quality	Qual	0.934	81.378			
		Morale	Moral	0.86	45.446			
		Material Handling Efficiency	MHEff	0.926	87.956			
		Lead Time Reduction	LdTmRe	0.919	86.942			

Bootstrapping was utilized to determine the t-statistics as indicators of significance. All values surpassed the 1.96 cutoff, meaning that the values were significant at a 95% confidence level or 0.5 level, as illustrated in Table 3 and Figure 2. Discriminant validity was examined by comparing the CR and AVE with the squared correlation of the latent variable, as illustrated in Table 4. All values for CR and AVE were greater than the squared interconstruct correlation values (off-diagonal in the correlation matrix). Therefore, a satisfactory level of discriminant validity can be confirmed.

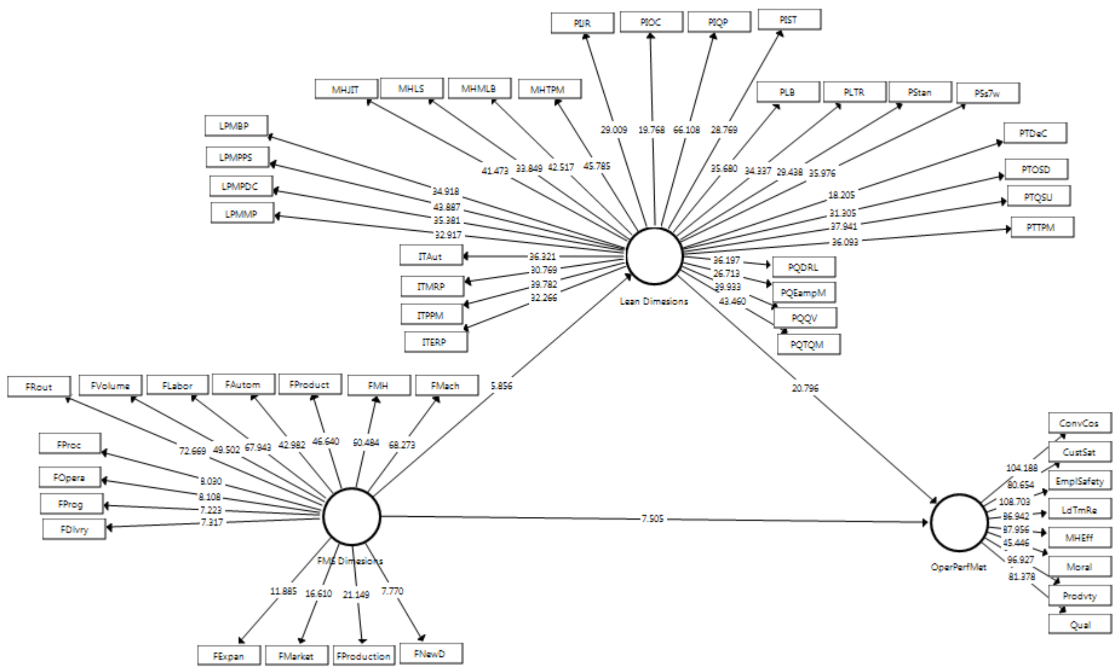

Fig. 2. Bootstrapping result at 1000 subsamples

Table 4. Discriminant validity of results

Construct	CR	FMS Dimensions	Lean Dimensions	OperPerfMet
FMS Dimensions	0.959	**0.74**		
Lean Dimensions	0.984	0.403	**0.855**	
OperPerfMet	0.983	0.591	0.827	**0.921**

4.2 Assessment of Common Method Variance

In order to develop the initial survey, two main steps were taken.

1- We utilized previous work conducted on the topic of flexibility and lean, such as Purvis et al. (2014), Ghosh (2013), Gunasekaran et al. (2008), Shah and Ward (2003), and Sethi and Sethi (1990).
2- We consulted with facility managers who were involved in LM and FMS implementation to determine which lean and flexibility dimensions had been implemented and what operational performance metrics had been utilized.

The initial survey was updated based on feedback obtained during a second interview with senior directors at the companies visited. For example, certain lean tools were added to the initial list and the directors indicated interest in placing the lean dimensions into categories, as illustrated in Table 3. Each interview/survey was conducted with a different senior manager at the facilities visited. Senior managers interviewed include facility, production, and engineering managers. Harman's single factor test was utilized to identify common method variance (Sreedevi & Saranga, 2017) and thus ensure there was no bias. The exploratory factor analysis (presented above) indicated that no single factor stood out. All factors presented had eigenvalues greater than one; therefore, common method bias was not an issue in this research.

4.3 Structure Model Assessment

Next, the significance of the path coefficients and the explanatory power was evaluated. No missing values were found in the sample of 164. Based on Wong (2013), we checked for possible collinearity using multiple regression via SPSS in order to evaluate the variance inflation factor (VIF). All VIF values were well below the cutoff point of 5, thus indicating no collinearity problem. Table 5 presents the structural model associated with the standardized coefficient, R^2, and the corresponding level of significance for the path model.

The empirical study presented investigated the mediating effect of LM on the relationship between FMS implementation and operational metrics in the automotive manufacturing industry. The hypothesized model explained 78.6% of the variance in operational performance metrics overall. When breaking these down into separate metrics, the model showed values ranging between R^2=0.521*** for morale to R^2=0.756*** for productivity, as illustrated in Table 5. Applying Stone–Geisser's blindfolding method (Henseler et al., 2009) showed a Q^2 value for operational performance metrics of 0.39. Similarly, when dividing the eight operational metrics separately we found that their associated values were 0.35, 0.32, 0.28, 0.39, 0.38, 0.34, 0.29, and 0.388, respectively, where the positive value is an indicator of satisfactory predictive power.

Table 5. Path model data outputs

Operational Performance Metrics	Flexibility Dimensions	Lean Dimensions
1 Quality (R^2=0.661***)	0.246***	0.683***
2 Productivity (R^2=0.756***)	0.391***	0.636***
3 Conversion Cost (R^2=0.726***)	0.325***	0.669***
4 Customer satisfaction (R^2=0.653***)	0.282***	0.828***
5 Lead Time Reduction (R^2=0.695***)	0.128**	0.775***
6 Material Handling Efficiency (R^2=0.661***)	0.333***	0.621***
7 Employee Safety (R^2=0.749***)	0.239**	0.742***
8 Morale (R^2=0.521***)	0.248***	0.433***

***P<0.01, **P<0.05, *P<0.1

In regards to H1, H2, and H3, the bootstrapping test indicated a value of 20.69 between the mediator (lean dimensions) and direct variable (DV) operational performance metrics, 7.090 between the indirect variable (IV) and DV, and 6.189 between the IV and mediator. All of these values are above the cutoff point of 1.96. The PLS algorithm test indicated that all dimensions for IV, DV, and mediator values were above 0.7 (cutoff point). The AVE, which measures the amount of variance due to the construct relative to the amount due to the measurement error, indicated a value of 0.683 for with rho (CR) of 0.984 and Cronbach's α of 0.983, 0.548 AVE with rho (CR) of 0.959 and Cronbach's α 0.935, and 0.848 AVE with rho (CR) of 0.983 and Cronbach's α 0.974 for mediator, IV, and DV respectively. The inner model analysis, specifically the R^2, demonstrated that an acceptable portion of variance in the DV construct could be explained by the model, as illustrated in Table 5. In addition, the AVE and CR values were larger than the squared interconstruct correlation values; these results support H1, H2, and H3.

The following are unique findings illustrated by the data analyses for the first three hypotheses:

- The highest value for t-statistics was for H1 (20.069), followed by H2 (7.1) and H3 (6.189).

- The lowest loading value for the lean dimensions was for open communication (0.728), and as a category in lean dimensions the lowest process technology was the lowest (0.80).
- The lowest value for loading in the flexibility dimensions was for new design (0.684), and as a category the lowest was strategic flexibility (0.732).
- The lowest value for loading in operational performance metrics was morale (0.86).

A similar trend was illustrated when comparing the t-statistic values for dimensions and categories, as illustrated in Table 3.

4.4 Mediator Analysis

Mediating effect can be tested by conducting a step-wise mediation analysis (Hair et al., 2014). This process requires the following steps:

1- Run the PLS algorithm to obtain the direct value with and without the mediator presence. This value indicates whether the presence of the mediator increases or decreases the value of the relationship.

2- Run bootstrapping to obtain the path coefficients (mean, standard deviation, t-values). The value will indicate the following relations: IV with mediator beta, mediator with DV, IV with mediator standard error, and mediator with direct standard error.

3- Run the Sobel test to determine whether the mediator carriers the influence of an IV to a DV. The Sobel test statistics value should be greater than 1.96, while the two-tailed probability should be less than 0.05 for 95% confidence (Sarwono, 2018; Hair et al., 2014).

Our analysis of the results is illustrated in Table 6. The direct value with the mediator was 0.597, which is greater than the direct value without the mediator, at 0.295. This indicates that the mediator increases the strength of the direct relation between the IV, FMS dimensions, and the DV, operational performance metrics. The t-statistics (IV to DV) indicate a value of 7.090 (bootstrapping), revealing a value above 1.96 and thus indicating significance at a 95% confidence level. The Sobel test results indicate a value of 6.105 (greater than 1.96), and a two-tailed probability of 0.00 (less than 0.05); therefore, we can conclude that the mediator does mediate the effect between the IV and DV, supporting H4.

Table 6. Results of PLS, bootstrapping, and Sobel test

Path Coefficients	
Direct value with Mediator	0.597
Direct Value with No Mediator	0.295
Indirect Variable ---> Med Beta	0.403
Med ---> direct Variable Beta	0.736
Indirect Variable ---> Med Stand error	0.063
Med ---> direct Variable Stand error	0.036

Sobel test output	
Sobel test statistic:	6.105
One-tailed probability:	0.000
Two-tailed probability:	0.000

5. Discussion and Conclusion

The empirical analysis conducted in this study clearly shows the mediating role that LM plays in the relationship between FMS implementation and operational performance metrics in the automotive manufacturing industry. This study is unique due to its depth and breadth in addressing the first three hypotheses, and is the first to conduct an empirical analysis into the relationship between lean, flexibility, and operational performance metrics. The dimensions investigated for these three main components were utilized based on what the automotive companies have implemented and currently use in their facilities. This study not only confirms the impact of lean and flexibility on operational performance metrics, but also provides empirical validation of the benefit of lean implementation on FMS and the impact of that implementation on organizational performance.

Ambiguity, uncertainty, and complexity are just few characteristics of today's markets. The continuous fluctuation in raw materials and oil prices directly impacts organizational profitability. According to IndustryWeek (2016), manufacturing companies are managing today's market volatility, price reduction pressures, and increasing oil and material costs by investing in new products and product technology, and improving internal production processes. Deloitte (2016) indicated that lean and flexibility are two key requirements for manufacturing survival in this era. The importance of flexibility lies in its ability to support organizational and operational performance. Manufacturing systems by nature are always subject to changes. These changes are controllable in some cases, but in most are not. Fluctuations in oil prices will force customers to change the product type purchased; for instance, if oil prices are high, customers will tend toward smaller cars, and vice versa. This in turn will require manufacturing facilities to adjust production from one type of vehicle to another, which also leads to changes in internal issues, such as materials, layout, operations, processes, routing, etc. Flexibility allows the process to adjust in order to compensate for such changes.

Researchers such as Yin et al. (2017), Hazen et al. (2017), Shukla and Wan (2010), Shah and Ward (2007), Slack (1983), Goldman and Nagel (1993), and Womack and Jones (1996), who conducted similar investigations (H1, H2, H3), though with limited breadth and depth in comparison to this research, have found similar results to ours. In-depth investigation related to H1, H2, and H3 indicate that not all dimensions react in the same direction. In order to test the impact of the dimension category on the overall model, we tested the output by deleting the category and rerunning the model. Ranked in order of importance by impact on loading averages and t-statistic values, the categories were ranked as follows: productivity, process quality, material handling, process management, people involvement, information technology, and process technology. For FMS, operational flexibility had the highest impact on the model, followed by tactical flexibility and strategic flexibility. The gap between the impact of tactical flexibility and strategic flexibility was fractional. Some dimensions had a negative impact on the category, as well as the latent variable. For example, new design flexibility had a negative impact on strategic flexibility, as well as the t-statistic values between FMS and LM, which were tested by deleting some of the dimensions and rerunning the model in SmartPLS. Similar results were founded by deleting standardized work, and the 5S and seven wastes. In support of research conducted by Shukla and Wan (2010), Soni and Kodali (2009), Stevenson and Spring (2007), and Kidd (1994), several flexibility dimensions, such as market, delivery (material), and program, had an insignificant impact on the overall model. Likewise, lean dimensions such as enterprise resource planning, job rotation, and decoupling had an insignificant impact on the overall model. This shows that investigating the relationship between lean and flexibility can lead to different conclusions based on which dimensions are utilized for the study. This study encompassed a wide range of dimensions, which is more practical and comprehensive since it listed the dimensions based on literature findings and facility managers' feedback on dimensions utilized and measured.

The above results were shared with managers previously interviewed at the facilities visited for feedback. The following list summarizes the comments made:

- Several flexibility dimensions negatively impact lean (but not necessarily operations performance metrics); for example, labor flexibility implementation requires people to be trained on multiple products, which will reduce worker efficiency because their efficiency could be 90% for product A 50% and for product B. Similarly, implementing routing flexibility will decrease equipment utilization. Both flexibilities will result in additional waste, and underutilized people and equipment.
- Initial lean implementation going back to the early 21st century entailed managers selecting specific dimensions and ignoring others. Therefore, the improvement results achieved in operational performance were mediocre (5–15% improvements). Later, management discovered that input from assembly line workers is critical for eliminating waste. Therefore, for success in productivity dimensions the implementation facility needs to utilize people-involvement dimensions. A comprehensive approach must be followed for successful lean implementation. This lesson is utilized when implementing FMS.
- Full implementation of LM and FMS does not necessary lead to improvements. Based on experience, not all lean and flexibility dimensions require full implementation to achieve the best performance. For example, cross-training and job rotation have been proven to have a negative impact in certain departments of the manufacturing assembly process. This is driven by job proximity and the type of job conducted at the different stations.

- Flexibility implementation entails high implementation costs, which cannot be justified based on cost–benefit analysis. For example, implementation of automation and expansion flexibility require drastic changes to the facility. According to engineering managers, implementation of FMS in brownfield (old) facilities has been proven to entail higher costs compared to implementing FMS in greenfield (new) facilities. Therefore, implementing certain FMS dimensions cannot be justified from a cost–benefit analysis. Indeed, when looking at the results of this research managers agreed that new design and market flexibilities were always given low priority in implementation due to their high cost. Similarly, lean dimensions such as decoupling will get less focus from managers due to the high implementation costs thereof.
- Union-related issues prevent full implementation of certain lean tools. When presenting the issues related to the low-level loadings for several lean dimensions, such as open communication, master planning, and job rotation, managers indicated that they have limited control over issues related to job rotation as union employees have the option to select different jobs based on seniority. In that case, training will not provide the required output since employees tend to move more frequently between departments.

Managers agreed (95% of managers interviewed) that lean plays a critical role in the relationship between flexibility implementation and operational metrics in the automotive manufacturing industry. They indicated that this is expected based on their experience in implementing both philosophies at their facilities. It was noted that managers believed in the ability of both philosophies to help achieve the highest performance possible. Managers indicated that in order to achieve the full potential, employee perceptions of LM and FMS must be changed. They indicated that employees look at LM and FMS as tools to eliminate jobs, rather than improve competitiveness. This is in line with previous research conducted by Schonberger and Brown (2017), Brusset (2016), Jasti and Kodali (2015), and Shah and Ward (2009).

The results clearly indicate that lean implementation is critical to insure optimal performance improvement through FMS implementation.

5.1 Managerial Implementation

This research empirically adds to the understanding of the impact of FMS on operational performance metrics and the mediating role that LM plays in that relationship. The paper provides managers with a framework that links LM to FMS, and outlines the role that each LM and FMS dimension plays in order to achieve the required performance metric improvements. The paper identifies several lean and flexibility dimensions that managers should consider and focus on when attempting to improve performance metrics in their manufacturing facilities.

5.2 Research Limitations

While flexibility includes 15 dimensions, LM encompasses 101 dimensions (Pavnakar et al., 2003). This research paper investigated the 15 flexibility dimensions, but only covered 28 types of lean dimensions and eight operational performance metrics identified by managers to be the most important. The findings have implications for practitioners in automotive manufacturing facilities in the US; however, similar studies should be conducted in other types of manufacturing companies in order to generalize the findings.

References

Agarwal, A., Shankar, R. and Tiwari, M.K. (2006), "Modelling the metrics of lean, agile and leagile supply chain: An ANP-based approach", *European Journal of Operations Research*, Vol. 173 No.1, pp. 211–225.

Anand, G. and Kodali, R. (2008), "A conceptual framework for lean supply chain and its implementation", *International Journal of Value Chain Management*, Vol. 2 No. 3, pp. 313–357.

Barbier, F. (2017), "World Economic Forum: Five Trends for the Future of Manufacturing", available at: https://www.weforum.org/agenda/2017/06/what-s-going-on-with-manufacturing-b013f435–1746–4bce-ac75–05c642652d42/ (accessed December 15, 2017).

Bortolotti, T., Boscari, S. and Danese, P. (2015), "Successful lean implementation: Organizational culture and soft lean practices", *International Journal of Production Economics*, Vol. 160, pp. 182–201.

Boyle, T. and Scherrer-Rathje, M. (2008), "An empirical examination of the best practices to ensure manufacturing flexibility lean alignment", *Journal of Manufacturing Technology Management*, Vol. 20 No. 3, pp. 348–366.

Brusset, X. (2016), "Does supply chain enhance agility?", *Int. J. Prod. Econ.*, Vol. 171, pp. 46–59.

Cachon, G. and Terwiesch, C. (2009), *Matching Supply and Demand*, International Edition, McGraw-Hill, Singapore.

Challis, D., Samson, D. and Lawson, B. (2005), "Impact of technological, organizational and human resource investments on employee and manufacturing performance: Australian and New Zealand evidence", *International Journal of Production Research*, Vol. 43 No. 1, pp. 81–107.

Christopher, M. and Towill, D. (2001), "An integrated model for the design of agile supply chains", *International Journal of Physical Distribution & Logistics Management*, Vol. 31 No. 4, pp. 235–246.

Coffman, D.L. and MacCallum, R.C. (2005), "Using parcels to convert path analysis models into latent variable models", *Multivariate Behavioral Research*, Vol. 40, pp. 235–259.

Cua, K.O., McKone, K.E. and Schroeder, R.G. (2001), "Relationships between implementation of TQM, JIT, and TPM and manufacturing performance", *Journal of Operations Management*, Vol. 19 No. 6, pp. 675–694.

Da Silveira, J.C. and Giovani, C.R. (2006), "The relationship between inter organizational information systems and operations performance", *International Journal of Operations and Production Management*, Vol. 26 No. 3, pp. 232–253.

Deloitte (2016), "Global Manufacturing Competitive Index", available at: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Manufacturing/gx-global-mfg-competitiveness-index-2016.pdf (accessed Jan 2, 2018).

EL-Khalil, R. (2009), "Optimization of flexible body shop system", available at https://search.proquest.com/docview/305050753?pq-origsite=gscholar (accessed Jan 1, 2018).

Faisal, M.N., Banwet, D.K. and Shankar, R. (2006), "Supply chain risk mitigation: Modelling the enablers", *Business Process Management Journal*, Vol. 12 No. 4, pp. 535–552.

Flynn, B.B., Sakakibara, S., Schroeder, R.G., Bates, K.A. and Flynn, E.J. (1995), "Relationship between JIT and TQM: Practices and performance", *Academy management Journal*, Vol. 38 No. 5, pp. 1325–1360.

Fornell, C. and Larcker, D.F. (1981), "Evaluating structural equation models with unobservable variables and measurement error", *Journal of Marketing Research*, pp. 39–50.

Fotopoulos, C.B. and Psomas, E.L. (2009), “The impact of “soft” and “hard” TQM elements on quality management results”, *International Journal of Quality & Reliability Management*, Vol. 26 No. 2, pp. 150–163.

Fullerton, R.R. and McWatters, C.S. (2002), “The role of performance measures and incentive systems in relation to the degree of JIT implementation”, *Accounting, Organizations and Society*, Vol. 27 No. 8, pp. 711–735.

Ghosh, M. (2013), “Lean manufacturing performance in India manufacturing plants”, *Journal of Manufacturing Management*, Vol. 24 No.1, pp. 113–122.

Goldman, S.L. and Nagel, R.N. (1993), “Management, technology and agility: The emergence of a new era in manufacturing”, *International Journal of Technology Management*, Vol. 8 No.1–2, pp. 18–38.

Goldsby, T.J., Griffis, S.E. and Roath, A.S. (2006), “Modelling lean, agile and leagile supply chain strategies”, *Journal of Business Logistics*, Vol 27 No.1, pp. 57–79.

Gunasekaran, A. (1999a), “Agile manufacturing: A framework for research and development”, *International Journal of Production Economics*, Vol. 62, pp. 87–105.

Gunasekaran, A. (1999b), “Design and implementation of agile manufacturing systems: editorial”, *International Journal of Production Economics*, Vol. 62, pp. 1–6.

Gunasekaran, A., Lai, K.-H., and Cheng, T.C.E. (2008), “Responsive supply chain: A competitive strategy in a net worked economy”, *Omega: The International Journal of Management Science*, Vol. 36 No. 4, pp. 549–564.

Hair, J.F., Hult, G.T.M., Ringle, C.M. and Sarstedt, M. (2014), “A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)”, *CA: SAGE Publication*.

Harrison, A. (1997), “From leanness to agility”, *Manufacturing Engineering,* Vol. 76 No. 6, pp. 257–260.

Hazen, T.B., Bradley, V.R., Bell, E.J., In, J. and Byrd, A.T. (2017), “Enterprise architecture: A competence-based approach to achieving agility and firm performance”, *International Journal of Production Economics*, Vol. 193, pp. 566–577.

Henseler, J., Ringle, C.M. and Sinkovics, R.R. (2009), “The use of partial least squares path modeling in international marketing”, *Advanced Interantional Marketing*. Vol. 20, pp. 277–320.

Herer, Y.T., Tzur, M. and Yucesan, E. (2002), “Trans shipments: An emerging inventory recourse to achieve supply chain agility”, *International Journal of Production Economics*. Vol. 80 No. 3, pp. 201–212.

Hormozi, A.M. (2001), “Agile manufacturing: The next logical step”, *Benchmarking: An International Journal*, Vol. 8 No. 2, pp. 132–143.

Huang, Y.Y. and Li, S.J. (2010), “How to achieve agility: A case study of a personal computer original equipment manufacturer in Taiwan”, *Journal of Manufacturing Systems*, Vol. 29 No. 2–3, pp. 63–70.

IndustryWeek. (2016), “The Future of Manufacturing 2020 and Beyond”, available at: https://www.nist.gov/sites/default/files/documents/2016/11/16/iw_kronos_research_report_2016.pdf (accessed December 18, 2017).

Inman, R.A., Sale, R.S., Green, K.W. and Whitten, D. (2011), “Agile manufacturing: Relation to JIT, operational performance and firm performance”, *Journal of Operations Management*, Vol. 29, pp. 343-355.

Jasti, N.V. and Kodali, R. (2015), “A critical review of lean supply chain management frameworks: Proposed framework”, *Production Planning Control*, Vol. 26 No.13, pp. 1051–1068.

Jin-Hai, Li, Anderson, A.R. and Harrison, R.T. (2003), “The evolution of agile manufacturing”, *Business Process Management*, Vol. 2 No.9, pp. 170–189.

Karim, A. and Arif-Uz-Zaman, K. (2013), “A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organization”, *Business Process Management Journal*, Vol. 19 No.1, pp. 169–196.

Katayama, H. and Bennett, D. (1999), “Agility, adaptability and leanness: A comparison of concepts and a study of practice”, *International Journal of Production Economics*, Vol. 60–61, pp. 43–51.

Kidd, P.T. (1994), “Agile Manufacturing: Forging New Frontiers”, *Reading, MA and Workingham: Addison-Wesley*.

Koste, L., Malhotra, M. and Sharma, S. (2004), “Measuring dimensions of manufacturing flexibility”, *Journal of Operations Management*, Vol. 22 No. 2, pp. 171–196.

Krishnamurthy, R. and Yauch, C.A. (2007), “Leagile manufacturing: A proposed corporate infrastructure”, *International Journal of Operations and Production Management*, Vol. 27 No.6, pp. 588–604.

Lucato, W.C., Calarge, A.C., Junior, M.L. and Calado, R.D. (2014), “Performance evaluation of lean manufacturing implementation in Brazil”, *International Journal Productivity and Performance Management*, Vol. 63 No. 5, pp. 529–549.

Mackelprang, A.W. and Nair, A. (2010), “Relationship between just-in-time manufacturing practices and performance: a meta analytic investigation”, *Journal of Operations Mannegement*, Vol. 28 No. 4, pp. 283–302.

Matsui, Y. (2007), “An empirical analysis of just-in-time production in Japanese manufacturing companies”, *International Journal of Production Economics*, Vol. 108 No. 1–2, pp. 153–164.

McCullen, P. and Towill, D. (2001), “Achieving lean supply through agile manufacturing”, *Integrated Manufacturing Systems*, Vol. 12 No. 7, pp. 524–533.

Narasimhan, R., Swink, M. and Kim, S.W. (2006), “Disentangling leanness and agility: An empirical investigation”, *Journal of Operations Management*, Vol. 24 No. 5, pp. 440–457.

Narain, R., Yadav, R.C., Sarkis, J. and Cordeiro, J.J. (2000), “The strategic implications of flexibility in manufacturing systems”, *International Journal of Agile Management Systems*, Vol. 2 No. 3, pp. 202–213.

Nawanir, G., Teong, L.K. and Othman, S.N. (2013), “Impact of lean practices on operations performance and business performance”, *Journal of Manufacturing Technology Management*, Vol. 24 No. 70, pp. 1019–1050.

Naylor, J.B., Naim, M.M. and Berry, D. (1999), "Agility: Integrating the lean and agile manufacturing paradigms in the total supply chain", *International Journal of Production Economics,* Vol. 62 No. 1/2, pp. 107–118.

Oke, A. (2013), "Linking manufacturing flexibility to innovation performance in manufacturing plants", *International Journal of Production Economics,* Vol. 143, pp. 242–247.

Pavnaskar, S.J., Gershenson, J.K. and Jambekar, A.B. (2003), "Classification scheme for lean manufacturing tools", *International Journal of Production Research*, Vol. 41 No. 13, pp. 3075–3090.

Perez, C., Castro, R., Simons, D. and Gimenez, G. (2010), "Development of lean supply chains: A case study of the Catalan pork sector", *Supply Chain Management International Journal,* Vol. 15 No. 1, pp. 55–68.

Purvis, L., Gosling, J. and Naim, M.M. (2014), "The development of a lean agile and agile supply network taxonomy based on differing types of flexibility", *International Journal of Production Economics,* Vol. 151, pp. 100–111.

Rahimnia, F. and Moghadasian, M. (2010), "Supply chain leagility in professional services: how to apply decoupling point concept in healthcare delivery system", *Supply Chain Management International Journal,* Vol. 15 No. 1, pp. 80–91.

Rahman, S. and Bullock, P. (2005), "Soft TQM, hard TQM, and organizational performance relationships: an empirical investigation", *Omega*, Vol. 33, pp. 73–83.

Riet, C., Clerck, D. and Demeulemeester, E. (2015), "Lean beyond Company Borders: Costs or Benefits?", available at: https://lirias.kuleuven.be/bitstream/123456789/478237/1/KBI_1502.pdf (accessed Feb 2, 2018).

Sajan, M.P., Shalij, P.R., Ramesh, A. and Biju, A, P. (2017), "Lean manufacturing practices in Indian manufacturing SMEs and their effect on sustainability performance", *Journal of Manufacturing Technology Management,* Vol. 28 No. 6, pp. 772–793.

Samson, D. and Terziovski, M. (1999), “The relationship between total quality management practices and operational performance”, *Journal of Operations Management,* Vol. 17, pp. 393–409.

Sarwono, J. (2018), *PLS SEM in Research Data Analysis Application,* Amazon.com, Inc, Washington, DC.

Schonberger, J.R. and Brown, A.K. (2017), “Missing link in competitive manufacturing research and practice: Customer-responsive concurrent production”, *Journal of Operations Management,* Vol. 49 No. 5, pp. 83–87.

Sethi, A.K. and Sethi, P.S. (1990), “Flexibility in manufacturing: A survey”, *International Journal of Flexible Manufacturing Systems,* Vol. 2, pp. 289–328.

Shah, R. and Ward, P.T. (2003), “Lean manufacturing: Context, practice bundles, and performance”, *Journal of Operations Management*, Vol. 21 No. 2, pp. 129–150.

Shah, R. and Ward, P.T. (2007), “Defining and developing measures of lean production”, *Journal of Operations Management,* Vol. 25, pp. 785–805.

Shukla, S.K. and Wan, H.D. (2010), “A leagile inventory-location model: Formulation and its optimization”, *Int. J. Oper. Res.,* Vol. 8 No. 2, pp. 150–173.

Slack, N. (1983), “Flexibility as a manufacturing objective”, *International Journal of Operations and Production Management,* Vol. 3 No. 3, pp. 4–13.

Slack, N. (1987), “The flexibility of manufacturing systems”, *International Journal of Operations and Production Management,* Vol. 7 No. 4, pp. 35–45.

Slack, N. (2005), “The changing nature of operations flexibility”, *International Journal of Operations and Production Management,* Vol. 25 No. 12, pp. 1201–1210.

Soni, G. and Kodali, R. (2009), “Performance value analysis for the justification of the agile supply chain”, *International Journal of Business Performance Management,* Vol. 11 No. 1–2, pp. 96–133.

Spear, S.J. and Bowen, H.K. (1999), “Decoding the DNA of the Toyota production system”, *Harvard Business Review,* Vol. 77 No. 5, pp. 97–106.

Sreedevi, R. and Saranga, H. (2017), “Uncertainty and supply chain risk: The moderating role of supply chain flexibility in risk Mitigation”, *International Journal of Production Economics*, Vol. 193, pp. 332–342.

Stevenson, M. and Spring, M. (2007), “Flexibility from a SC perspective: Definition and review”, *International Journal of Operations and Production Management,* Vol. 27 No. 7, pp. 685–713.

Taj, S. (2008), “Lean manufacturing performance in China: Assessment of 65 manufacturing plants”, *Journal of Manufacturing Technology Management,* Vol. 19 No. 2, pp. 217–234.

Taylor, D. (2006), “Strategic considerations in the development of lean agri-food supply chains: A case study of the UK pork sector”, *Supply Chain Management International Journal,* Vol. 11 No. 3, pp. 271–280.

Taylor, W.A. and Wright, G.H. (2006), “The contribution of measurement and information infrastructure to TQM success”, *Omega*, Vol. 34, pp. 372–384.

Theagarajan, S. and Manohar, H. (2015), “Lean management practices to improve supply chain performance of leather footwear industry”, *2015 International Conference on Industrial Engineering and Operations Management*, Dubai, United Arab Emirates.

Towill, D.R. and Christopher, M. (2002), “The supply chain strategy conundrum: To be lean or agile or to be lean and agile?”, *International Journal of Logistics Research and Application,* Vol. 5 No. 3, pp. 299–309.

Upton, D. (1994), “The management of manufacturing flexibility”, *Calif. Management Review,* Vol. 36 No. 2, pp. 72–89.

Vazquez-Bustelo, D., Avella, L., and Fernandez, E. (2007), “Agility drivers, enablers and outcomes”, *International Journal of Operations and Production Management,* Vol. 27 No. 12, pp. 1303–1332.

Vokurka, J.R. and O’Leary-Kelly, W.S. (2000), “A review of empirical research on manufacturing flexibility”, *Journal of Operations Management,* Vol. 18, pp. 485–501.

Vonderembse, M.A., Uppal, M., Huang, S.H. and Dismukes, J.P. (2006), “Designing supply chains: towards theory development”, *International Journal of Production Economics,* Vol. 100 No. 2, pp. 223–238.

Wei, Z., Song, X., and Wang, D. (2017), “Manufacturing flexibility, business model design, and firm performance”, *International Journal of Production Economics,* Vol. 193, pp. 87-97.

Wickramasinghe, G.L.D. and Wickramasinghe, V. (2017), “Implementation of lean production practices and manufacturing performance”, *Journal of Manufacturing Technology Management,* Vol. 28 No. 4, pp. 531–550.

Wikner, J. and Rudberg, M. (2005), “Integrating production and engineering perspectives on the customer order decoupling point”, *International Journal of Operations and Production Management,* Vol. 25 No. 7, pp. 623–641.

Womack, J.P. and Jones, D.T. (1996), *Lean Thinking—Banishing Waste and Creating Wealth in Your Corporation*, New York, NY: Simon and Schuster.

Wong, K.K.K. (2013), “Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS”, *Market. Bull.*, Vol. 24 No. 1, pp. 1–32.

Yin, Y., Stecke, E.K., Swink, M. and Kaku, I. (2017), “Lessons from seru production on manufacturing competitively in a high cost environment”, *Journal of Operations Management,* Vol. 49 No. 51, pp. 67–76.

Zhang, Z. and Sharifi, H. (2007), “Towards theory building in agile manufacturing strategy—A taxonomical approach”, *IEEE Transactions on Engineering Management,* Vol. 54 No. 2, pp. 351–370.

Appendix

Table A1: Sample of lean, flexibility, and metrics addressed by survey questionnaire

					C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
			Lean Dimensions												
Lean Dimensions	1	Process Management	1	Business Plan Deployment	5	5	5	5	5	5	5	5	5	5	5
			2	Master Planning	5	5	5	5	5	5	5	5	5	5	5
			3	PDCA (Plan-Do-Check-Act)	5	5	5	5	5	5	5	5	5	5	5
			4	Practical Problem Solving	4	4	4	4	4	4	4	4	4	4	4
	2	People Involvement	1	Small Team Concept	4	4	4	4	4	4	4	4	4	4	4
			2	Open Communication	5	5	5	5	5	5	5	5	5	5	5
			3	Job Rotation	4	4	4	4	4	4	4	4	4	4	4
			4	Qualified People	4	4	4	4	4	4	4	4	4	4	4
	3	Process Quality	1	Error and Mistake Proofing	3	3	3	3	3	3	3	3	3	3	3
			2	Quality Verification Station	4	4	4	4	4	4	4	4	4	4	4
			3	Direct Run Loss	5	5	5	5	5	5	5	5	5	5	5
			4	Total Quality Maintenance (TQM)	4	4	4	4	4	4	4	4	4	4	4
	4	Material Handling/Supply Chain	1	JIT Center	4	4	4	4	4	4	4	4	4	4	4
			2	Material Line Balance	4	4	4	4	4	4	4	4	4	4	4
			3	Scheduled Shipping and Receiving	4	4	4	4	4	4	4	4	4	4	4
			4	Level Scheduling	5	5	5	5	5	5	5	5	5	5	5
	5	Process Technology	1	De-Coupling	4	4	4	4	4	4	4	4	4	4	4
			2	TPM	4	4	4	4	4	4	4	4	4	4	4
			3	Quick Set Up	4	4	4	4	4	4	4	4	4	4	4
			4	Operator Support Devices	4	4	4	4	4	4	4	4	4	4	4
	6	Information Technology	1	Enterprise resource planning-System	5	5	5	5	5	5	5	5	5	5	5
			2	Material Requirement Planning-System	5	5	5	5	5	5	5	5	5	5	5
			3	Production Planning and Monitoring system	5	5	5	5	5	5	5	5	5	5	5
			4	Autonomation	3	3	3	3	3	3	3	3	3	3	3
	7	Productivity	1	Standardization	5	5	5	5	5	5	5	5	5	5	5
			2	5S and 7 Waste	5	5	5	5	5	5	5	5	5	5	5
			3	Lead Time Reduction	5	5	5	5	5	5	5	5	5	5	5
			4	Line Balancing	4	4	4	4	4	4	4	4	4	4	4
			Flexibility Dimensions												
Flexible Mfg			1	Machine	4	4	4	4	4	4	4	4	4	4	4
			2	Material Handling/Delivery	5	5	5	5	5	5	5	5	5	5	5
			3	Operation	4	4	4	4	4	4	4	4	4	4	4
			4	Automation	4	4	4	4	4	4	4	4	4	4	4
			5	Labor	4	4	4	4	4	4	4	4	4	4	4
			6	Process	4	4	4	4	4	4	4	4	4	4	4
			7	Routing	4	4	4	4	4	4	4	4	4	4	4
			8	Product	3	3	3	3	3	3	3	3	3	3	3
			9	New design	2	2	2	2	2	2	2	2	2	2	2
			10	Material	4	4	4	4	4	4	4	4	4	4	4
			11	Volume	3	3	3	3	3	3	3	3	3	3	3
			12	Expansion	4	4	4	4	4	4	4	4	4	4	4
			13	Program	3	3	3	3	3	3	3	3	3	3	3
			14	Production	3	3	3	3	3	3	3	3	3	3	3
			15	Market	2	2	2	2	2	2	2	2	2	2	2
			Operational Metrics												
Metrics			1	Quality	5	5	5	5	5	5	5	5	5	5	5
			2	Customer satisfaction	3	3	3	3	3	3	3	3	3	3	3
			3	Conversion Cost	4	4	4	4	4	4	4	4	4	4	4
			4	Productivity	4	4	4	4	4	4	4	4	4	4	4
			5	Lead Time Reduction	4	4	4	4	4	4	4	4	4	4	4
			6	Material Handling Efficiency	5	5	5	5	5	5	5	5	5	5	5
			7	Employee Safety/Injury Rate	4	4	4	4	4	4	4	4	4	4	4
			8	Employee Moral	2	2	2	2	2	2	2	2	2	2	2

Table A2: Measurement results: Basic statistics

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
ConvCos <- OperPerfMet	0.938	0.938	0.009	104.188	0
CustSat <- OperPerfMet	0.92	0.919	0.011	80.654	0
EmplSafety <- OperPerfMet	0.945	0.945	0.009	108.703	0
FAutom <- FMS Dimesions	0.866	0.866	0.02	42.982	0
FDlvry <- FMS Dimesions	0.475	0.468	0.065	7.317	0
FExpan <- FMS Dimesions	0.636	0.635	0.054	11.885	0
FLabor <- FMS Dimesions	0.898	0.898	0.013	67.943	0
FMH <- FMS Dimesions	0.885	0.885	0.015	60.484	0
FMach <- FMS Dimesions	0.909	0.909	0.013	68.273	0
FMarket <- FMS Dimesions	0.692	0.689	0.042	16.61	0
FNewD <- FMS Dimesions	0.514	0.511	0.066	7.77	0
FOpera <- FMS Dimesions	0.515	0.513	0.063	8.108	0
FProc <- FMS Dimesions	0.522	0.52	0.065	8.03	0
FProduct <- FMS Dimesions	0.856	0.857	0.018	46.64	0
FProduction <- FMS Dimesions	0.757	0.755	0.036	21.149	0
FProg <- FMS Dimesions	0.51	0.504	0.071	7.223	0
FRout <- FMS Dimesions	0.897	0.896	0.012	72.669	0
FVolume <- FMS Dimesions	0.879	0.878	0.018	49.502	0
ITAut <- Lean Dimesions	0.832	0.831	0.023	36.321	0
ITERP <- Lean Dimesions	0.829	0.83	0.026	32.266	0
ITMRP <- Lean Dimesions	0.829	0.83	0.027	30.769	0
ITPPM <- Lean Dimesions	0.842	0.841	0.021	39.782	0
LPMMP <- Lean Dimesions	0.793	0.793	0.024	32.917	0
LPMPDC <- Lean Dimesions	0.834	0.834	0.024	35.381	0
LPMPPS <- Lean Dimesions	0.854	0.854	0.019	43.887	0
LdTmRe <- OperPerfMet	0.919	0.919	0.011	86.942	0
MHEff <- OperPerfMet	0.926	0.926	0.011	87.956	0
MHJIT <- Lean Dimesions	0.866	0.866	0.021	41.473	0
MHLS <- Lean Dimesions	0.814	0.812	0.024	33.849	0
MHMLB <- Lean Dimesions	0.874	0.873	0.021	42.517	0
MHTPM <- Lean Dimesions	0.878	0.877	0.019	45.785	0
Moral <- OperPerfMet	0.86	0.861	0.019	45.446	0
P5s7w <- Lean Dimesions	0.843	0.842	0.023	35.976	0
PIJR <- Lean Dimesions	0.822	0.821	0.028	29.009	0
PIOC <- Lean Dimesions	0.728	0.726	0.037	19.768	0
PIQP <- Lean Dimesions	0.902	0.902	0.014	66.108	0
PIST <- Lean Dimesions	0.818	0.817	0.028	28.769	0
PLB <- Lean Dimesions	0.829	0.829	0.023	35.68	0
PLTR <- Lean Dimesions	0.808	0.808	0.024	34.337	0
PQDRL <- Lean Dimesions	0.823	0.823	0.023	36.197	0
PQEampM <- Lean Dimesions	0.802	0.8	0.03	26.713	0
PQQV <- Lean Dimesions	0.839	0.838	0.021	39.933	0
PQTQM <- Lean Dimesions	0.869	0.868	0.02	43.46	0
PStan <- Lean Dimesions	0.773	0.772	0.026	29.438	0
PTDeC <- Lean Dimesions	0.729	0.728	0.04	18.205	0
PTOSD <- Lean Dimesions	0.813	0.813	0.026	31.305	0
PTQSU <- Lean Dimesions	0.82	0.82	0.022	37.941	0
PTTPM <- Lean Dimesions	0.844	0.844	0.023	36.093	0
Prodvty <- OperPerfMet	0.923	0.924	0.01	96.927	0
Qual <- OperPerfMet	0.934	0.934	0.011	81.378	0
LPMBP <- Lean Dimesions	0.813	0.811	0.023	34.918	0