Lean Manufacturing, Non-Financial Performance Measures, and Financial Performance

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ABSTRACT

Purpose – This paper examines how utilization of non-financial manufacturing performance (NFMP) measures impacts the lean manufacturing/financial performance relationship.

Design/methodology/approach – A structural equation model (SEM) is estimated using data provided by 121 U.S. manufacturing executives. In addition to examining direct effects, the study examines whether NFMP measurement mediates or moderates the lean manufacturing/financial performance relationship.

Findings – The results provide substantial evidence that utilization of NFMP measures mediates the relationship between lean manufacturing and financial performance.

Research implications/limitations – The study's findings regarding NFMP measurement suggest that the mixed results of prior studies of the lean manufacturing/financial performance relationship may be due in part to a failure to account for NFMP measurement. Limitations of the study are the non-random sample and its small sample size, relative to the SEM estimated.

Practical implications – Managers who implement lean manufacturing without utilizing supportive NFMP measures may experience disappointing financial results.

Originality/value – This is the first known study that adopts a SEM framework to examine: 1) how NFMP measurement affects the relationship between lean production and profitability; 2) the direct relationship between NFMP measurement and firm performance; and 3) the impact of lean manufacturing on externally audited, objective measures of firm performance

Keywords – Non-financial performance measures, Lean manufacturing, Structural equation modeling

Paper type – Research paper

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Introduction

Toyota Motor Company's original just-in-time (JIT) philosophy has evolved into a lean production paradigm that has transformed the U.S. manufacturing landscape. But evidence on lean production's financial performance effects is mixed (e.g., Callen et al., 2000; Kinney and Wempe, 2002; Lau, 2002; Eriksson and Hansson, 2003; Fullerton et al., 2003; Nahm et al., 2003; Ahmad, et al., 2004; York and Miree, 2004; Boyd, et al., 2006; Wayhan and Balderson, 2007). Shah and Ward (2007) attribute some variation in prior results to inconsistency among researchers regarding the definition and components of "lean production." Cua et al. (2001) assert that variation in performance effects is due in part to managers' piecemeal adoption of lean production's various components. Contextual factors may also contribute to variation in lean production's performance effects. For example, Balakrishnan et al. (1996) report smaller financial benefits for JIT adopters with concentrated customer bases, and Hendricks and Singhal (2001) find that many contextual factors impact TQM's performance effects.

Methodological inconsistencies, piecemeal adoption, and contextual factors all likely contribute to variation in lean manufacturing's documented performance effects. This study focuses on an additional source of variation: utilization of non-financial manufacturing performance (NFMP) measures in support of lean initiatives. The study's central hypothesis posits that tracking, reporting, and analyzing NFMP measures provides crucial, actionable information in lean environments, and that NFMP measurement mediates the relationship between lean production and financial performance.

This study uses structural equation modeling (SEM) to examine the relationships depicted in Figure 1. The primary contribution of this research is its examination of the effects on financial performance from including NFMP measures in firms' management accounting systems (MAS). Included in this examination is a detailed analysis of whether NFMP measurement's role in the relationship between lean manufacturing and financial performance is more consistent with a mediating perspective or a moderating perspective. In addition, this is the first known study to use SEM to investigate the direct effects of lean production methods and NFMP measurements on externally-audited, objective measures of financial performance.

[Take in Figure 1.]

Results from estimating the SEM with data collected from 121 U.S. manufacturing executives support the following conclusions. Consistent with prior studies, shop-floor employee involvement is positively associated with implementation of lean initiatives, which in turn is positively associated with utilization of NFMP measures. The direct relationships between lean practices and profitability are generally significant when no NFMP measurement mediator is present, but insignificant when the NFMP measurement variable is included in SEM and regression-based tests. Finally, the results indicate that utilization of NFMP measures is positively associated with financial performance.

This study's key finding is that utilization of NFMP measures mediates the association between lean manufacturing and financial performance. Results from two types of tests support this inference. First, results for the SEM depicted in Figure 1 indicate that each of the three lean practices has a positive indirect effect (through NFMP measures) on financial performance. This suggests that lean methods are effective when supported by NFMP measurement. In addition, regression-based tests find significant support for the prediction that utilization of NFPM measures *mediates* the association between lean methods and financial performance. This finding of a mediating role for NFPM measurement is consistent with decades-old calls for changes in MAS to support modern manufacturing practices (e.g., Kaplan, 1983; Goldratt and Cox, 1984), and clearly has implications for managers contemplating best practices in the employment of lean production. Moreover, the mediation finding may shed new light on the inconsistent results of prior studies that examine the relationships between financial performance and lean strategies without considering the corresponding alignment of NFMP measures.

The next section examines prior research and develops the research hypotheses. The following section describes the survey instrument, summarizes the data collection process, and presents empirical results. These are followed by a discussion of the results and the final section, which provides a concluding summary.

Hypotheses development

Shop-floor employee involvement

In lean production settings, where excess inventory or other buffers are not available to counter production or quality failures, employees must have the ability and authority to make decisions. Badore (1992) describes shop-floor employees' unique understandings of their work environments as an important element of such decisions. Koufteros et al. (1998) characterize employee involvement as an antecedent to adoption of time-based manufacturing methods, and Boyer (1996) finds that companies committed to lean production devote resources to train and empower their workforces. Several studies conclude that employee involvement is a critical element of the successful adoption of JIT and/or TQM (Ishikawa, 1985; Deming, 1986; Anderson et al., 1994; Wruck and Jensen, 1994; Powell, 1995; Ahire and O'Shaughnessy, 1998; Cua et al., 2001; Fullerton and McWatters, 2002; Agus, 2005). Consistent with prior research, the first hypothesis is:

H1a: Shop-floor employee involvement is positively associated with implementation of *lean activities to reduce setup times.*

H1b: Shop-floor employee involvement is positively associated with implementation of *cellular manufacturing*.

H1c: Shop-floor employee involvement is positively associated with implementation of *lean activities to improve production quality.*

Lean manufacturing and NFMP measures

The appropriate design of a MAS is dependent upon the environment in which it operates (Kaplan, 1983; Johnson and Kaplan, 1987; Fisher, 1992; Chenhall, 2003; Abdel-Maksoud et al., 2005). The argument has persisted for decades that traditional MAS designed to support mass production are neither timely nor sufficiently comprehensive to provide the type of critical decision-making information that is required in current world-class manufacturing environments (Kaplan, 1983, Johnson, 1990; Vollman, 1990). MAS focused on variance analysis and aggregating costs may distort manufacturing performance in lean environments (Baines and Langfield-Smith, 2003) and are inconsistent with technologies emphasizing cross-functional coordination, flexibility, and responsiveness to customers (Abernethy and Lillis, 1995). Ittner and Larcker (1998) describe adoption of non-financial performance measures as an outgrowth of initiatives such as TQM, which require detailed process information that is often not available from aggregate accounting data.

Fullerton and McWatters (2002, 2004) and Abdel-Maksoud et al. (2005) find that utilization of advanced manufacturing technologies is associated with greater reliance on non-financial performance measures. Daniel and Reitsperger (1991) and Ittner and Larcker (1997) show that firms pursuing quality strategies use control systems that incorporate quality-related practices, and Banker et al. (1993) report that feedback is more frequent in firms using JIT, TQM, and teamwork.

It is expected that implementation of lean initiatives induces firms to increase their use of NFMP measures in order to provide relevant, actionable information to employees working in environments focused on flexibility, quality, and responsiveness. The second hypothesis is:

> **H2a**: Implementation of *lean activities to reduce setup times* is positively associated with *utilization of NFMP measures*.

> **H2b**: Implementation of *cellular manufacturing* is positively associated with *utilization of NFMP measures*.

> **H2c**: Implementation of *lean activities to improve production quality* is positively associated with *utilization of NFMP measures.*

Lean manufacturing practices and financial performance

Customers today demand high quality products with varying production requirements, and often require deliveries in small lot sizes with short lead times. In response to these demands, manufacturers have adopted initiatives related to setup time reduction, cellular manufacturing, and quality improvement. Production in smaller lot sizes requires more frequent setups. Therefore, reducing setup time (and cost) is increasingly necessary to serve customers timely and profitably. Further, firms limited to mass production capabilities are often ill-equipped to compete in today's marketplace. Consequently, many firms have sought the flexibility and efficiency associated with cellular manufacturing. Finally, a greater concern with quality on the part of customers has led manufacturers to invest in quality initiatives to retain and expand their customer bases and to reduce the costs associated with quality failures.

Lean methods entail both costs and benefits. Therefore, their effect on net financial performance is an empirical question. Results from prior studies are mixed. Several studies report that adopting JIT or TQM does not improve profitability (e.g., Huson and Nanda, 1995; Ittner and Larcker, 1995; Mohrman et al., 1995; Balakrishnan et al., 1996; Lau, 2002; Ahmad, et al., 2004). However, other research finds support for a positive association between modern manufacturing practices and financial performance (e.g., Chenhall, 1997; Easton and Jarrell, 1998; Callen et al., 2000, 2003; Kinney and Wempe, 2002; Eriksson and Hansson, 2003; Fullerton et al., 2003; Kaynak, 2003; Nahm et al., 2003). To examine the direct effects of lean manufacturing practices on financial performance, the third hypothesis is:

H3a: Implementation of *lean activities to reduce setup times* is positively associated with profitability.

H3b: Implementation of *cellular manufacturing* is positively associated with profitability.

H3c: Implementation of *lean activities to improve production quality* is positively associated with profitability.

NFMP measures and financial performance

Ittner and Larcker (1998) identify the effectiveness of non-financial performance measures as an important research topic. Yet, a significant void in the literature persists (Chenhall and Moers, 2007). Information is a powerful tool for substantially influencing corporate performance (Mangaliso, 1995), and performance measurement must provide feedback that reflects outcomes important to enhancing performance (Chenhall, 1997).

Without proper information, it is difficult for managers to make good decisions and respond to situations appropriately. Said et al. (2003) maintain that non-financial performance measures provide a means of transforming a firm's strategy and vision into a tool that motivates performance and communicates strategic intent. Earley et al. (1990, 102) demonstrate how appropriate feedback acts to enhance performance by acting as a "cueing device or tool for strategy implementation." Firms that fail to measure those areas that are most critical to its success are less likely to achieve their strategic objectives (Sim and Killough, 1998; Baines and Langfield-Smith, 2003). Further, Fisher (1992) contends that firms tracking key success factors through non-financial performance measures have superior financial results.

A substantial body of organizational behavior literature (e.g., Erez, 1977; Ilgen et al., 1979; Locke and Latham, 1990, 2002; Neubert, 1998) suggests that goal attainment is facilitated by the provision of feedback. Feedback helps workers adjust their strategies and the level or direction of their effort, which in turn enhances performance (Ilgen et al., 1979; Earley et al., 1990; Locke and Latham, 1990, 2002). While the expectation is that the utilization of NFMP measures should assist companies in achieving their performance objectives, the limited empirical evidence on such measurement's financial performance effects is mixed. Ittner and Larcker (1995) report that greater utilization of non-financial measures is associated with improved financial performance in settings lacking formal quality programs, but not in settings having such programs. Perera et al. (1997) report increased usage of non-financial measures among companies adopting advanced manufacturing technologies, but report no association with firm performance. Likewise, Callen et al. (2000) find that non-financial performance indicators are unrelated to profits in both JIT and non-JIT firms.

Other studies provide evidence of a positive relationship between the scope of firms' MAS and their financial performance. Durden et al. (1999), Baines and Langfield-Smith (2003), and Said et al. (2003) find that increased reliance on non-financial measures is associated with improved performance. Similarly, Van der Stede et al. (2006) report that firms with performance measurement diversity report stronger performance. Finally, Callen et al. (2005) find that in both JIT and non-JIT plants, increasing the breadth of performance measures used correspondingly increases financial performance.

It is anticipated that shop-floor employees and managers glean relevant insights from NFMP measures. Specifically, H4 posits that NFMP measures provide granular, actionable information that can be used by shop-floor employees and managers to improve their firms' financial performance. The fourth hypothesis is:

H4: Utilization of *NFMP measures* is positively associated with profitability.

Lean manufacturing, NFMP measures, and financial performance: mediating effects

Xu et al. (2006) note that when hypothesizing that the effect of one variable on another variable is contingent on a third variable, it is common to adopt either a *moderation* perspective or a *mediation* perspective. Organizational behavior research generally assigns a *moderating* role to feedback in goal-setting and performance contexts (e.g., Earley et al., 1990). However, this study posits that utilization of NFMP measures *mediates* the lean manufacturing/financial performance relationship. This prediction is not without difficulty. On one hand, the model posits that lean manufacturing utilization induces firms to conduct NFMP measurement (i.e., H2). But on the other hand, the model predicts (in H5 below) that cross-sectional variation in firms' utilization of NFMP measures to support lean manufacturing will explain variation in financial performance. Hartmann (2005) asserts that no single theory can make these "fit" and "performance" predictions simultaneously.

Despite these concerns, the study adopts a mediation perspective for four reasons. First, few strategies can be successful over time without a means of providing relevant and actionable feedback to the employees who are responsible for executing the strategies. Studies have found that organizations adjust their MAS to meet their strategic needs (e.g., Bouwens and Abernethy, 2000; Gerdin, 2005). There is a recognized "need for congruence between management accounting and production systems from both a conceptual and practical basis" (Durden et al., 1999, p. 112). Mia (2000) suggests that performance-related information provided by MAS is critical to JIT firms because they have minimal slack. Chenhall and Langfield-Smith (2007) concur that MAS should coordinate and combine financial and non-financial measures within an integrative strategic framework that accommodates new manufacturing technologies. Thus, it is understandable why utilization of NFMP measures, which provides employee feedback, is *critical* for lean initiatives to positively impact financial performance.

Second, contingency theory assumes that firms implement optimal MAS, but also allows for the likelihood that suboptimal MAS are used in some firms for extended periods of time (Donaldson, 1996; Luft and Shields, 2003). According to Luft and Shields (2003), an appropriate setting for examining the "fit" and mediation hypotheses simultaneously is where many firms use suitable MAS, but many firms do not. The present setting reasonably approximates the setting described by Luft and Shields (2003).

Thus, examining the direct relationship between lean practices and utilization of NFMP measures, as well as the role of NFMP measurement in the lean practices/financial performance relationship, is appropriate.

Third, the model depicted in Figure 1 posits a causal relationship between lean production and the use of NFMP measures. The model also posits a causal relationship between the use of NFMP measures and firms' performance. According to Baron and Kenney (1986) and Gerdin (2005), neither prediction is consistent with the assumptions of a moderation model, in which a posited moderator should be theoretically unrelated to both the antecedent and criterion variables. Hartmann and Moers (2003, 807) describe the "puzzling paradox" of moderation models that suggest the *ex-ante* assumption that MAS are unaffected by firm's production strategies;, yet, claim *ex-post* that they should be. In contrast, in the posited mediated relationship, the use of NFMP measures should be an independent contributor to financial performance (H4) and also dependent upon the firm's production technology (H2). The mediation model supported by Barron and Kenney (1986) and Gerdin (2005) is shown in Figure 2.

[Take in Figure 2.]

Finally, regardless of the theoretical perspective adopted in examining the role of NFMP measurement in the lean manufacturing/financial performance relationship, empirical methods are available to assess whether the data available are consistent with that perspective. This study includes an SEM-based assessment of a mediating role for utilization of NFMP measures, as well as regression-based tests of whether a mediation or moderation perspective is more consistent with the data. This multi-perspective analysis is consistent with Venkatraman (1989), who suggests that testing different forms of fit with the same data should produce more robust findings.

Prior MAS-related research has adopted both mediator and moderator perspectives. Chong and Chong (1997) use path analysis to show that performance effects from business unit strategy and environmental uncertainty are primarily indirect through firms' MAS. Gerdin (2005) finds that departmental interdependence impacts subunit performance through the indirect effects of MAS. Two regression-based MAS studies that adopt a moderation perspective are Mia (2000) and Chenhall (1997). Mia (2000) examines the provision of MAS information as a determinant of the profitability of JIT adopters and non-adopters, and finds that the profit of JIT adopters (but not non-adopters) increases as the level of information provided via the MAS increases. Chenhall (1997) shows that the relationship between TQM and financial performance is influenced by the level of reliance on manufacturing performance measures. On the other hand, Durden et al. (1999) found a direct relationship between the use of non-financial performance measures and performance, but no significant effect on profitability from the interaction of JIT and the use of these measures (moderating effect). Ittner and Larcker (1995) had similar results, with the *interaction* of extensive use of non-financial measures and TQM practices actually lowering profitability.

As Chenhall and Langfield-Smith (2007) note, the effect on performance from the use of NFMP measures in support of advanced technologies remains ambiguous. To address this ambiguity, the final and most pivotal hypothesis of this study examines the mediating effects of NFMP measurement in the relationship between lean manufacturing practices and financial performance. That is, the study considers whether initiatives for setup time reduction, cellular manufacturing, and quality improvement have indirect performance consequences through NFMP measurement. Support for the hypothesis would be consistent with NFMP measurement serving a critical role in the success of lean initiatives. The fifth hypothesis is:

H5a: The association between firm profitability and *lean activities to reduce setup times* is mediated through utilization of NFMP measures.

H5b: The association between firm profitability and *cellular manufacturing* is mediated through utilization of NFMP measures.

H5c: The association between firm profitability and *lean activities to improve production quality* is mediated through utilization of NFMP measures.

Research methods

Survey instrument

This study examines, cross-sectionally, the financial performance effects from joint utilization of lean manufacturing and NFMP measures. The observed variables are adapted from previous studies. The lean, time-based manufacturing measures of shop-floor employee involvement, and initiatives to reduce setup times, implement cellular manufacturing, and improve production quality were developed by Koufteros et al. (1998). While these four constructs are not all-encompassing of a lean strategy, they are important elements representative of the lean production system (see Papadopoulou and Ozbayrak, 2005; Shah and Ward, 2007). The modified NFMP measures are adapted from Fullerton and McWatters (2002).[1] The individual items that measure these five constructs are shown in the Appendix.

The study's survey instrument is a revised version of an instrument used in earlier published studies. The revisions include the addition of the Koufteros et al. (1998) time-based (lean) manufacturing measures. Following the initial changes, feedback was solicited from selected business professors and from managers of four manufacturing firms that were familiar with lean manufacturing strategies. Appropriate suggested modifications were made to the survey instrument.

The initial sample for this study constituted 253 pre-identified executives from manufacturing firms responding to an earlier (1997) questionnaire.[2] Of the original 253 respondent firms, 66 (26%) were no longer independent businesses. Of these 66 firms, 26 were out of business, 38 were acquired, and two had gone private. In addition, over one-half of the individual initial respondents in the 187 remaining firms were no longer with their companies. Replacement contacts were identified in all but ten firms. Thus, 177 manufacturing executives were contacted a maximum of three times via the Internet, faxes, or mail. One hundred twenty-one usable responses were received, for an overall response rate of 68 percent. The majority of the respondents had titles equivalent to Vice President of Operations, Director of Manufacturing, or Plant Manager. They had an average of 19 years of management experience, including 12 years with their current firms.

Respondent firms have primary two-digit SIC codes within the manufacturing range of 20-39. As shown in Table I, 70 percent of the respondent firms are from four industries: chemicals and allied products (SIC-28, 8 percent), industrial machinery (SIC-35, 16 percent), electronics (SIC-36, 26 percent), and instrumentation (SIC-38, 20 percent), which is similar to the sampling distribution and the related COMPUSTAT population.

To check for non-response bias, an ANOVA analysis compared the sales and profitability measures of non-respondents to those of respondents. No significant differences were found. To check for survivorship bias, ANOVA analyses examined the 253 firms in the original survey and compared the sales and profitability measures of those that were contacted in this study to those that were not. Only sales showed a significant difference ($p < 0.05$), with mean net sales for this sample exceeding mean net sales of the original sample. The sample was also compared to the total COMPUSTAT population of manufacturing firms. *T*-tests show that the net sales of the sample firms is significantly smaller ($p = 0.05$) than that of the total population. This difference can be explained by the parameters set in the original sample selection, which excluded firms with sales over $2 billion. However, there are no statistically significant return on sales (ROS) differences in comparisons of respondents to non-respondents, or sample to total population.

[Take in Table I.]

Reliability and validity tests

Exploratory factor analysis

To reduce and summarize the data and establish the unidimensionality of the individual variables, the survey items were subjected to an exploratory factor analysis. Using the principal components method with a Varimax rotation, five factors emerged with eigenvalues in excess of 1.0 explaining 68 percent of the variance. These factors were in alignment with *a priori* expectations. One item (determines factory layout from product families) had cross-loadings on two lean constructs, and three of the 11 items intended to measure NFMP loaded on multiple factors. These four items were eliminated from further analyses. The loadings for each of the elements are shown in parentheses in the Appendix. The factor solutions for the defined constructs support the construct validity of the survey instrument. Multiple-question loadings for each factor in excess of 0.50 demonstrate convergent validity (see Bagozzi and Yi, 1988). In addition, discriminant validity is supported, since none of the questions in the factor analyses have loadings in excess of 0.40 on more than one factor. Cronbach's alpha (1951) is used as the coefficient of reliability for testing the internal consistency of the constructs. As shown in Table II, the correlation coefficients for all factors are significant, and the alpha coefficients exceed 0.80, above the acceptable standard of 0.70 for established constructs (Nunnally and Bernstein, 1994).

[Take in Table II.]

Confirmatory factor analysis

The measurement model using the scales resulting from the exploratory factor analysis was evaluated per a confirmatory factor analysis (CFA) (Gerbing and Anderson, 1988). Schumacker and Lomax (1996, p. 72) recommend a two-step modeling approach proposed by James et al. (1982) that first evaluates the measurement model to assure its fit and then examines the full structural model. The measurement model provides an assessment of convergent and discriminant validity and the structural model provides an assessment of predictive validity. Jöreskog and Sörbom (1993, p. 113) indicate that the measurement model must be tested independently before testing the structural model in order to determine whether the chosen indicators for a construct measure that construct. The maximum likelihood (ML) approach in AMOS 7 was used to test the measurement model and full structural model. Among the 121 respondents, most measures have a full response, with no more than two responses missing for any single measure. AMOS does not evaluate missing data, but provides a theoretical approach to random missing data that is “efficient and consistent, and asymptotically unbiased” (Byrne, 2001, 292).

Where covariances were suggested by AMOS and justified theoretically, they were included between error terms of the same construct (see Baines and Langfield-Smith, 2003; Jaworski and Young, 1992; Shields et al., 2000).[3] All of the structural models are over-identified and recursive.

The measurement model fit (as defined by Hair et al., 1998) was evaluated using a number of fit indices, including: X^2 and the ratio of X^2 to degrees of freedom; Root Mean Square Error of Approximation (RMSEA); goodness of fit index (GFI) (Jöreskog and Sörbom, 1981); incremental fit index (IFI) (Bollen, 1989); Tucker-Lewis Index (TLI) (Tucker and Lewis, 1973); Comparative Fit Index (CFI) (Bentler, 1990), and Akaike information criterion (AIC) (Akaike, 1987). Small *p*-values for the X^2 would indicate that the hypothesized structure is not confirmed by the sample data (Hughes et al., 1986). However, Jöreskog and Sörbom (1989) note that this statistic should be interpreted with caution, and that other measures of fit should be considered, such as the ratio of X^2 to degrees of freedom. RMSEA is one of the most informative criteria in assessing model fit (Byrne, 2001), with a built-in correction for model complexity (Kline 2005, p. 137). A RMSEA value of less than .08 is reasonable, although many view a value of .05 or less as indicating a good fit (Browne and Cudeck, 1993; Byrne, 2001; Kline, 2005). The other ratios (TLI, CFI, and IFI) are evaluated for their closeness to 1.0, and are preferred fit indices for small sample sizes (Shah and Goldstein, 2006). In addition, the AIC, which compares the hypothesized sample model to a hypothetical random sample (saturated) model, was also used to measure model parsimony (Kline, 2005, p. 142). The AIC of the hypothesized model should be less than that of the saturated model, since the model with the smallest AIC is the one most likely to replicate (Byrne, 2001; Hu and Bentler, 1995; Kline, 2005). The measurement model has good fit indices, as shown in Table III.

[Take in Table III.]

Convergent validity is evident when multiple attempts at measuring the same constructs produce the same results (Bagozzi et al., 1991). Convergent validity was evaluated with the fitted residual matrix and the standardized coefficients of the construct indicators. None of the standardized residuals in the fitted residual matrix were large enough ($> |2.58|$) to demonstrate potential areas of model misfit per Jöreskog and Sörbom (1988), and all of the modification indices are < 10. In addition, as indicated in Table III, all of the standardized coefficients are highly significant at $p < 0.001$, again indicating convergent validity.

Discriminant validity is concerned with assuring that the measures of the individual constructs are discrete (Bagozzi et al., 1991). Crocker and Algina (1986) indicate that discriminant validity is shown when the correlations of individual factors do not exceed the reliability coefficients. All of the correlation coefficients shown in Table II are less than the reliability coefficients. Further evidence of discriminant validity is to demonstrate that each variable is unique from the other variables. To evaluate this, “pairwise tests” of each individual measure were performed (Bagozzi and Phillips, 1982; Escrig-Tena and Bou-Llusar, 2005). Each paired measurement scale was evaluated with constrained and unconstrained covariances. The difference between the chi-squared values of the ten constrained and unconstrained models from the five paired constructs were evaluated. All of the tests showed significant differences ($p < 0.001$) between the chi-squares, supporting discriminant validity. Multivariate multicollinearity in the measurement model was assessed by examining tolerance factors and variance inflation factors. None of the variance inflation factors exceeded 2.0 and the tolerance statistics were all under 1.0, indicating multicollinearity is not a concern.

Profitability measure

The dependent variable used to represent firm profitability is *return on sales (ROS)*, measured as the ratio of income before extraordinary items to net sales. *ROS* was chosen for three reasons: 1) it is widely accepted as a measure of profitability; 2) it was determined to be the driver of ROA improvement for JIT adopters in Kinney and Wempe (2002); and 3) it eliminates some of the confounding effects in ROA arising from reduced inventories. ROS was obtained from COMPUSTAT for 2001, corresponding to the survey data collection period. To control for outliers in the data, the measure was winsorized at ten and 90 percent. Return on assets (the ratio of income before extraordinary items to total assets) and cash flow margin (the ratio of income before extraordinary items, plus depreciation and amortization, to net sales) were also analyzed in the structural model, with qualitatively similar results.

Fitness of the structural equation model

Before the path coefficients can be assessed, the fitness of the structural model must be evaluated. As shown in Table IV, the goodness-of-fit statistics generally indicate a good fit to the data. Although the X^2 is significant, the X^2 ratio is less than two, indicating an acceptable fit (Kline, 2005). Each of the remaining model fit indices shown in Table IV (IFI, TLI, and CFI) exceeds the acceptable fit level of 0.90, and the RMSEA does not exceed the acceptable fit measure of 0.08 (Browne and Cudeck, 1993). AMOS calculates a 90% confidence interval for the population parameter estimated by the RMSEA. The low to high range for the model's RMSEA is 0.023 to 0.061, which indicates that the model has close approximate fit in the population (see Byrne, 2001; Kline, 2005). In addition, the probability value that the model is a close fit is 0.684. Jöreskog and Sörbom (1996) suggest that the *p*-value for this test should be > 0.50. Further, parsimony is demonstrated by an AIC that is lower than that for the saturated model.

[Take in Table IV.]

Test results of the structural equation models

To evaluate the mediating effects of NFMP measures, the structural model was initially estimated without the NFMP construct. The standardized coefficients for the partial model are shown in Figure 3. Hypotheses 1a, 1b, and1c are supported, showing consistently significant coefficients ($p < 0.01$) in both the reduced (Figure 3) and full (Figure 1 and Table IV) structural models. These results replicate and confirm similar relationships examined in previous studies. The paths linking lean manufacturing methods to firm performance have varying significance levels in the reduced model. Cellular manufacturing shows the strongest significant relationship to ROS, supporting Hypothesis 2b. Setup reduction has a marginally significant relationship with ROS, and quality initiatives demonstrates no significance.

[Take in Figure 3.]

The ML results for the full structural equation model that includes the NFMP construct are shown in Table IV.[4] The paths between all three of the lean manufacturing practices and NFMP measures are significant, supporting Hypotheses 2a, 2b, and 2c. The use of NFMP measures is positively related to *ROS*, supporting H4. In the full structural model, none of the lean manufacturing practices have a significant relationship with ROS. Based on tests of mediation outlined by Baron and Kenny (1986), these results support Hypotheses 5a and 5b, but not Hypothesis 5c. According to Baron and Kenny (1986), for mediation to be indicated, the lean manufacturing variables must first demonstrate a significant relationship with the outcome variable (profitability) in a model that excludes the mediator variable (see H3 in Figure 2). In the second test of mediation, there must be a significant relationship between the mediator variable (NFMP measures) and the outcome variable (*ROS*) (see H4 in Figure 2), as well as significant relationships between the independent (lean) variables and the mediator variable (see H2 in Figure 2). The last evaluator of mediation is the direct relationship in the full model between the lean initiatives and profitability. If this relationship is no longer significant and the other tests are satisfied, full mediation has occurred. If the relationship shows a reduction in significance, there is partial mediation.

The mediation results show that the use of NFMP measures fully mediates the relationships between initiatives related to setup time reduction and profitability and the use of cellular manufacturing and profitability. Using the Baron and Kenny (1986) tests, mediation in the quality improvement/profitability relationship does not occur because there is no significant relationship in the initial direct test between the two variables. However, other studies indicate that full mediation does not require that the independent and dependent variable have a significant relationship in the absence of the mediator (Venkatraman, 1989; MacKinnon et al., 2000; Shrout and Bolger, 2002; Preacher and

Hayes, 2004; Gerdin, 2005). Under this interpretation, NFMP measures also fully mediate the relationship between quality improvement initiatives and profitability.

To further examine the effects of mediation under the Barron and Kenny (1986) approach, multiple linear regressions (MLR) were estimated. The initial MLRs examine the relationships between the individual lean practices (setup time reduction, cellular manufacturing, and quality initiatives) and ROS. Similar to the results from the reduced SEM model, setup time and cellular manufacturing have significant associations with ROS, but quality initiatives do not (see Table V). Next, the extent of NFMP measurement was regressed on the three lean initiatives. The results show that all three lean practices have significant associations with the extent of NFMP measurement ($p<0.01$; see Table V). The final MLRs regress ROS on both the lean practices and the extent of NFMP measurement. The results shown in Table VI demonstrate that the extent of NFMP measurement has a significant relationship to ROS in all three equations ($p<0.01$), and cellular manufacturing has a marginally significant relationship ($p<0.10$) to ROS when the extent of NFMP measurement is also included in the equation.[5] When the three lean variables and NFMP are included as independent variables in a single regression model, the results are the same. Additionally, the results of two-tailed Sobel tests (1986) also suggest that NFMP measurement mediates the profitability relationship for all three lean practices (see Table VI).

[Take in Table V and Table VI.]

In Table VII, the direct, indirect, and total effects for the full structural equation model provide additional analysis of the mediated relationships between lean manufacturing variables and *ROS* (note the direct effects in Table VII are the same as those shown in Table IV). Preacher and Hayes (2004) maintain that, compared to the regression analysis recommended by Baron and Kenny (1986), examining indirect effects is more effective in testing for mediation. Further supporting a mediation inference, the indirect effect of each lean practice is positive and significant at $p < 0.05$ or better.[6]

Overall, these results provide strong support for Hypotheses 5a and 5b, and some support for Hypothesis 5c, indicating that lean manufacturing practices are effective when accompanied by the complementary use of performance measures that provide informative and motivating information in world-class manufacturing environments.

[Take in Table VII.]

Discussion

Several of the relationships in Figure 1 have been examined previously. Tests of H1 (employee involvement in lean initiatives) and H2 (use of NFMP measures in lean environments) add to prior research examining new production technologies and evolution in firms' MAS.

The performance effects of lean practices (H3) have also been subjects of considerable prior research, although the results remain inconclusive. This study's tests of H3 in a structural equation framework and with an objective, externally-audited measure of financial performance, help clarify previous findings. Further, the results provide some rationale as to why some studies may have found little if any relationship between lean production and profitability. According to the results found here, the relationship is mediated by a measurement system that motivates behavior aligned with strategic objectives.

The relationship between financial performance and utilization of NFMP measures (H4) has been investigated to a lesser extent. While this remains an important research topic, evidence of a direct association between the application of NFMP measures and performance is at best mixed, with most studies failing to provide evidence of a positive association (Chenhall and Moers, 2007). Both SEM and MLR results in this study confirm that the use of NFMP measures has a direct effect on firm performance, and support Durden et al.'s (1999) conclusion that non-financial performance measures are an integral part of *any* effective MAS.

The primary contribution of this study is its examination of NFMP measurement as a potential source of variation in lean strategies' financial performance effects. Based on the results of both SEM and regression-based tests, NFMP measurement appears to *mediate* the relationship between lean manufacturing and financial performance. This conclusion raises two fundamental questions. First, what is implied conceptually when NFMP measurement is deemed to mediate, rather than moderate the lean production/financial performance relationship? Second, at an operational level, how does utilization of NFMP measures serve a mediating role?

Conceptually, this study's inferences in an operations setting mirror those drawn by Xu et al. (2006) in a marketing setting, where global organizational structure and global management processes are examined as possible sources of variation in the relationship between standardized marketing strategies and firm performance. Analogous to their findings, the results in the present study imply that the use of NFMP measures in lean production settings is *not a case of "more is better,"* where utilization of NFMP measures simply strengthens the magnitude of a positive relationship between lean strategies and financial performance. Instead, what the mediation results suggest is that *NFMP measures are a key component for financial success from the implementation of lean strategies*. This conclusion clearly assigns a crucial role to NFMP measurement in lean settings, supporting Gerdin's (2005) assertion that an expanded MAS encourages behaviors that enhance performance. It also may provide an explanation for why Durden et al. (1999) and Ittner and Larcker (1995) found no correlation between enhanced performance and the *interaction* of JIT/TQM with non-financial measures.

It should be noted that the data do *not* measure whether or not lean strategies improve NFMP measures. Nor do the data measure respondent firms' 'scores' on NFMP measures. The mediation finding simply suggests that *conducting NFMP measurement provides crucial and actionable information to shop-floor employees and managers in lean environments, and that this crucial feedback is a catalyst that allows the positive effects from lean strategies to transit to firm profitability*.

Shah and Ward (2007, 791) describe lean production as "an integrated socio-technical system whose main objective is to eliminate waste…" In such systems, many of the buffers engineered into traditional mass production systems (e.g., extra inventory, high capacity equipment, or a many-tiered supplier base) are deemed wasteful and are reduced or eliminated. Two important phenomena follow this transformation. First, the production system becomes a transparent one in which problems can no longer be hidden or ignored via buffers. Second, traditional MAS devoted to calculating and reporting aggregate cost variances are wasteful and no longer provide the type of relevant feedback needed by managers to maintain the efficiency, quality, customer responsiveness, and supplier relationships necessary to remain competitive in their markets. Thus, one of the most important areas for the successful adoption of lean strategies is the corresponding change in the MAS that reflects a firm's key performance measures (DeLuzio, 1993).

Simply eliminating buffers does not *solve* production, quality, or delivery problems – it merely *reveals* them. The results of this study suggest that, in lean environments, NFMP measurement provides the type of granular and actionable feedback needed by shop-floor employees and managers to address the root causes of problems and achieve success with lean strategies (whether NFMP measurement is construed as occurring within a "MAS" or within a broader control system is largely irrelevant to the finding of a mediating role for NFMP measurement). For example, for firms to achieve financial benefits from initiatives related to setup time reduction, managers must implement measures that monitor setups, throughput, and cycle times. Likewise, when firms organize production around product families, they benefit from measures that assess productivity, efficiency, waste, and timeliness. Finally, an appropriate measurement system that monitors quality improvement initiatives with production efficiency and productivity controls may mitigate the previously-documented negative effects of excessive or piecemeal investment in quality applications (Cammarano, 1996; Fullerton et al., 2003; Nakamura et al., 1998). As Conti (1993, p. 193) stressed, "NFMP measures can ensure that the interface between various aspects of the manufacturing process become areas for cooperation, and this assists in evaluating overall strategic plans and programs likely to affect long-term profitability."

Summary

This study contributes to our understanding of the relationships among lean manufacturing practices, utilization of NFMP measures, and firm profitability. Results of the study confirm that shop-floor employee involvement is critical to the successful adoption of lean production, and that lean production methods encourage the use of NFMP measures. Lean practices related to setup time reduction, cellular manufacturing, and quality improvement initiatives have varied direct effects on profitability, whereas utilization of NFMP measures has a significant direct effect on profitability. Most important, the evidence suggests that the use of NFMP measures mediates the effects that lean production initiatives have on firm profitability. This finding may partially explain the mixed results of prior research that examines performance effects of lean strategies but does not consider the composition of the MAS used to support these strategies.

Several limitations of the study may reduce the generalizability of its findings. As in all survey research, a necessary assumption in data collection was that the respondents had sufficient knowledge to answer the items, and that respondents answered the questions conscientiously and truthfully. Although a glossary accompanied the questionnaire, respondents' interpretations of terminology may have differed from that intended. Further, the sample is a subset of a previous research sample; thus, the sampling was not random and the resulting sample is of limited size. In addition, the size of the sample firms contacted was limited due to the ability to contact appropriate respondents and summarize the results from a single plant. Thus, compared to the overall population, the sample over-represents smaller firms. Finally, limitations of the study are not restricted to sample-related issues. While the empirical evidence in this study supports a mediating and not a moderating role for NFMP measurement in the lean manufacturing/financial performance relation, we recognize that theoretical justification for the moderation perspective remains viable. In particular, prior research in organizational behavior typically posits a moderating role for feedback (such as that provided by NFMP measures) in the attainment of goals (Locke and Latham, 2002).

There remain many unanswered questions related to lean production and its impact on performance. If a more definitive association between lean strategies and profitability could be established, such strategies would be more widely and rapidly adopted. It would also be useful to develop a clearer understanding of: 1) why firms implement lean production (e.g., to improve profitability or to respond to competitive upheaval); 2) which combination of lean practices most significantly impact performance; and 3) whether or not the order of implementation of such practices affects the success or failure of a lean initiative. Future research could also examine whether specific MAS intervene in the relationships between profitability and the ten lean constructs identified by Shah and Ward (2007), and explicitly examine the form of such intervention (e.g., moderation versus mediation). Further, in studying the information role of NFMP measurement, clearly delineating the types of relationships with the various forms (outcome and process) of feedback (e.g., Earley et al., 1990) may produce improved insights into the performance effects of lean manufacturing strategies. Finally, it would be interesting to evaluate how the market reacts to firms' commitments to the lean philosophy, and whether utilization of supporting management accounting practices has either direct or indirect effects on market-based performance measures. Continued research efforts are needed to provide a better understanding of the MAS' relevance and potential impact on continuous improvement initiatives in lean environments.

Appendix

~Survey Items Measuring Structural Equation Model Constructs

Shop-Floor Involvement

Indicate the extent to which your firm does the following:

Involves shop-floor employees in:

SF1. Problem-solving efforts (0.847)
SF2. Suggestion programs (0.775)
SF3. Designing processes and tools for improvement (0.748)
SF4. Problem-solving teams (0.729)

Setup Time Reduction

Indicate the extent to which your firm does the following:

SU1. Redesigns equipment to shorten setup time (0.722)
SU2. Uses special tools to shorten setup time (0.811)
SU3. Trains employees to reduce setup time (0.735)
SU4. Redesigns jigs or fixtures to shorten setup time (0.725)

Cellular Manufacturing

Indicate the extent to which your firm does the following:

*__CM1.__ Groups equipment into product families

Groups into families products that have:

CM2. Similar processing requirements (0.876)
CM3. Similar routing requirements (0.847)
CM4. Similar designs (0.578)

Quality Improvement

Indicate the extent to which your firm does the following:

QI1. Conducts process capability studies (0.799)
QI2. Uses designs of experiments (*Taguchi* method) (0.767)
QI3. Uses statistical process control (SPC) charts (0.699)

Non-Financial Manufacturing Performance Measures

How extensively are the following performance measures used in evaluating your manufacturing system?

*__NFMP1.__ Inventory turns
NFMP2. Equipment downtime (0.613530)
NFMP3. On-time delivery (0.721)
NFMP4. Scrap (0.753)
NFMP5. Rework (0.758)
NFMP6. Setup times (0.609)
NFMP7. Labor productivity (0.736)
NFMP8. Throughput time (0.658)
NFMP9. Manufacturing cycle efficiency (0.632)
***NFMP10.** Vendor performance – Product Quality
***NFMP11.** Vendor performance – On-time delivery

Numbers in parentheses represent loadings from Varimax rotation of exploratory factor analysis.

~Possible responses: Not at all = 1; Little = 2; Some = 3; Considerably = 4; Extremely = 5

*These items did not load as expected in an exploratory factor analysis, and thus were not included in the structural equation model.

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Model of Lean Manufacturing Practices, Non-Financial Manufacturing Performance Measures, and Firm Profitability

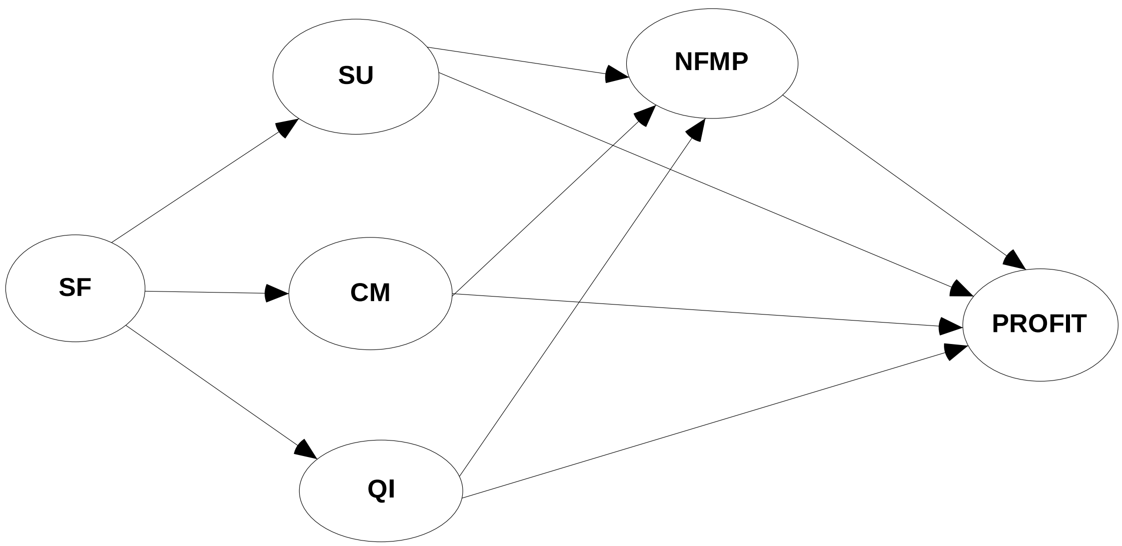

Figure 1

SF = Shop-floor employee involvement in problem solving
SU = Setup time reduction
CM = Cellular manufacturing
QI = Quality improvement
NFMP = Non-financial manufacturing performance measures
PROFIT = Return on sales

Mediation Research Model

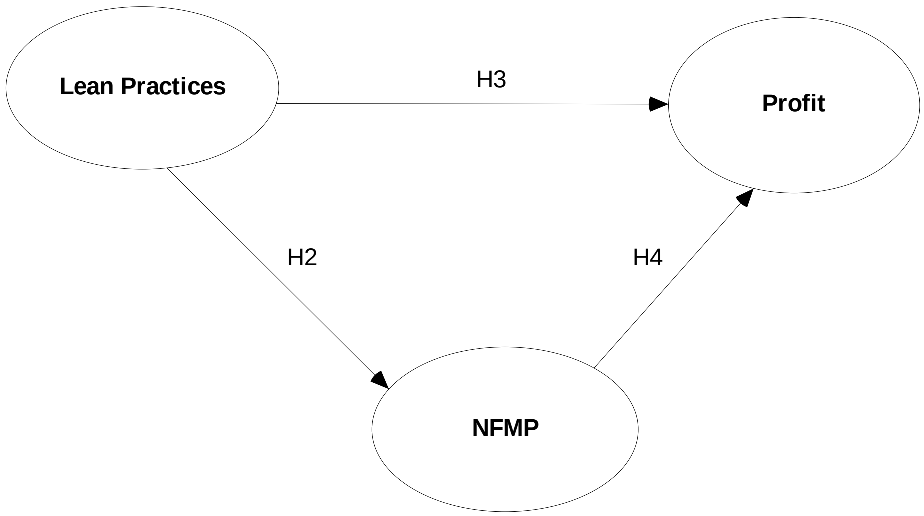

Figure 2

Lean Practices = Setup time reduction, Cellular manufacturing, and Quality improvement
NFMP = non-financial manufacturing performance measures
PROFIT = Return on sales

Reduced Model of Lean Manufacturing Practices and Firm Profitability

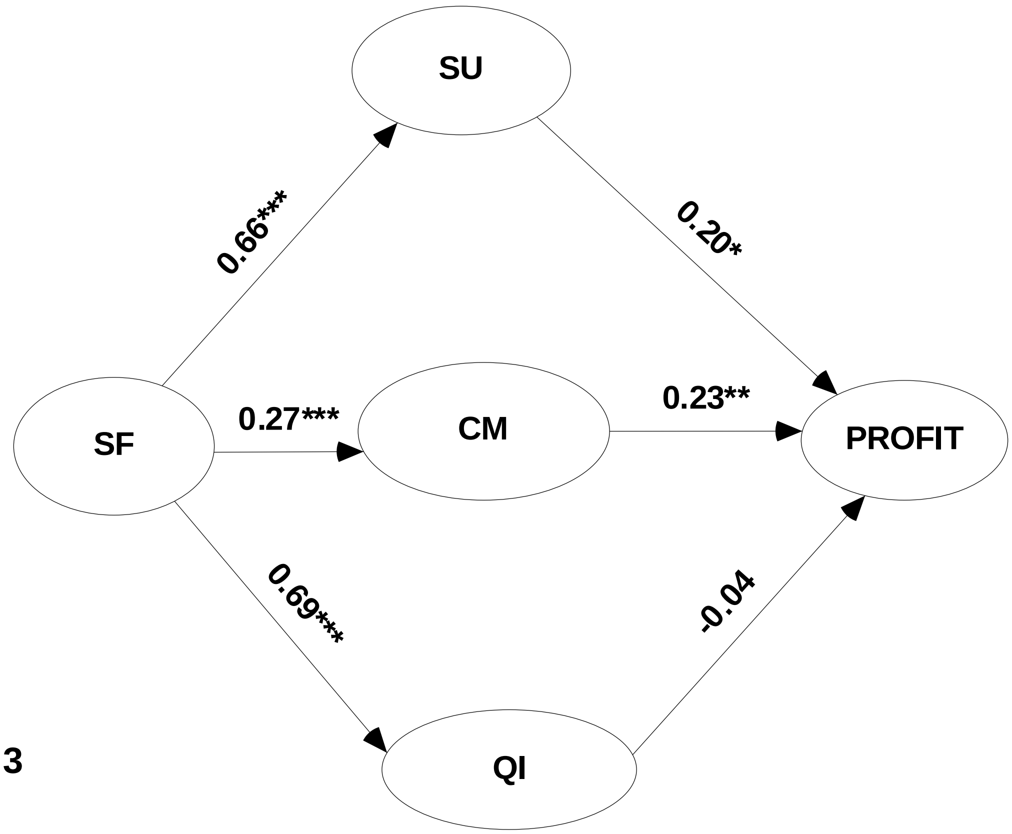

Figure 3

SF = Shop-floor employee involvement in problem solving
SU = Setup time reduction
CM = Cellular manufacturing
QI = Quality improvement
PROFIT = Return on sales

***p < 0.10, **p < 0.05, ***p < 0.01**

Fit Indices: Chi-square, 102.174; df, 84; p, 0.086; Chi-square ratio, 1.22; IFI, 0.982; TLI, 0.977; CFI, 0.981; RMSEA, 0.042, AIC, 204.174 (saturated model, 270.00)

Table I

Distribution of sample firms by two-digit SIC codes

Industry	Total Firms	Percent Responses	Percent Original Sample[a]
20 – Food	4	3.0	2.8
22 – Textiles	1	0.8	2.0
25 – Furniture & Fixtures	5	4.1	2.4
26 – Paper & Allied Products	2	1.7	0.8
27 – Printing/Publishing	1	0.8	0.4
28 – Chemicals & Allied Products	10	8.3	9.5
30 – Rubber Products	1	0.8	2.0
33 – Primary Metals	9	7.4	5.9
34 – Fabricated Metals	7	5.8	5.5
35 – Industrial Machinery	19	15.7	16.2
36 – Electronics	32	26.5	24.1
37 – Motor Vehicles & Accessories	4	3.3	4.3
38 – Instrumentation	24	19.8	21.7
39 – Other Manufacture	2	1.7	2.4
Totals	**121**	**100.0**	**100.0**

[a]n = 253

Table II

Correlation Coefficients, Descriptive Statistics, and Cronbach's Alpha

	# Measures	1	2	3	4	5	Mean	S.D.	Cr. α
1. SF	4	1.00					3.610	0.83	0.85
2. SU	4	0.54**	1.00				3.254	0.90	0.87
3. CM	3	0.23*	0.32**	1.00			3.719	1.14	0.94
4. QI	3	0.50**	0.48**	0.28**	1.00		2.803	1.24	0.80
5. NFMP	8	0.33**	0.51**	0.33**	0.43**	1.00	3.750	0.75	0.86
6. ROS	1	0.21*	0.22*	0.27**	0.10	0.15	0.396	9.06	N/A

Notes:

n =121

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

SF = Shop-floor employee involvement in problem solving
SU = Setup time reduction
CM = Cellular manufacturing
QI = Quality improvement
NFMP = Non-financial manufacturing performance measures
ROS = Return on sales

Table III

Results from Confirmatory Factor Analysis

Summary Data for Individual Construct Indicators

Construct Indicators	Standardized Coefficients (loadings)	*t*-values (all significant to *p* <0.000)
Shop-floor Employee Involvement		
SF4	0.852	--[a]
SF3	0.783	9.340
SF2	0.757	8.705
SF1	0.761	8.760
Lean Manufacturing Practices		
SU4	0.857	--[a]
SU3	0.788	9.607
SU2	0.805	10.437
SU1	0.840	10.652
CM4	0.923	--[a]
CM3	0.888	15.090
CM2	0.935	16.974
QI3	0.638	--[a]
QI2	0.800	6.686
QI1	0.839	6.839
Non-financial Manufacturing Performance Measures		
NFMP2	0.548	--[a]
NFMP3	0.521	4.343
NFMP4	0.692	5.106
NFMP5	0.636	4.978
NFMP6	0.680	6.243
NFMP7	0.704	5.372
NFMP8	0.755	5.441
NFMP9	0.694	5.174

Notes: n = 121 Measurement models are estimated using maximum likelihood.

See Appendix for definition of individual indicators from survey data.

[a] Indicates a parameter that was fixed at 1.0

Model fit indices: Chi-square, 210.635; degrees of freedom, 190; *p*, 0.145; Chi-square ratio, 1.109; IFI, 0.986; TLI, 0.983; CFI, 0.986; RMSEA, 0.031; AIC, 380.635, (saturated model, 550.00)

Table IV

Test Results of the full Structural Equation Model -- Direct Effects

Relationships	Hypothesis[a]	Standardized Coefficient	Confidence Intervals[b]	*t*-values
SF → SU	H1a	0.653	0.489, 0.780	6.511***
SF → CM	H1b	0.269	0.085, 0.451	2.699***
SF → QI	H1c	0.677	0.546, 0.785	5.435***
SU → NFMP	H2a	0.337	0.158, 0.531	3.125***
CM → NFMP	H2b	0.198	0.028, 0.355	2.272**
QI → NFMP	H2c	0.335	0.121, 0.513	2.905***
SU → ROS	H3a	0.061	-0.183, 0.298	0.550
CM → ROS	H3b	0.140	-0.020, 0.303	1.546
QI → ROS	H3c	-0.187	-0.429, 0.058	-1.591
NFMP → ROS	H4	0.433	0.233, 0.794	3.252***

Notes:

n = 121. Measurement models are estimated using maximum likelihood.

[a]All hypotheses are predicted to have positive relationships

[b]Confidence intervals (90%) were supplied by bootstrapped sample

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Model fit indices: Chi-square, 266.322; degrees of freedom, 215; *p*, 0.010; Chi-square ratio, 1.239; IFI, 0.967; TLI, 0.960; CFI, 0.966; RMSEA, 0.045; AIC, 434.322, (saturated model, 598.00)

R^2 for endogenous variables: Setup time reduction, 0.427; Cellular manufacturing, 0.072; Quality improvement, 0.458; Non-financial manufacturing performance measures, 0.413

SF = Shop-floor employee involvement in problem solving
SU = Setup time reduction
CM = Cellular manufacturing
QI = Quality improvement
NFMP = Non-financial manufacturing performance measures
ROS = Return on sales

Table V
Regression Results for Preliminary Mediation Tests

	Dependent Variable	Independent Variables	Coefficient	Adjusted R^2
H2				
	NFMP	SU	0.512***	0.256
	NFMP	CM	0.328***	0.100
	NFMP	QI	0.426***	0.174
H3				
	ROS	SU	0.217**	0.039
	ROS	CM	0.274***	0.067
	ROS	QI	0.100	0.001
H4				
	ROS	NFMP	0.361***	0.123

Notes: n = 121 * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

SU = Setup time reduction
CM = Cellular manufacturing
QI = Quality improvement
NFMP = Non-financial manufacturing performance measures
ROS = Return on sales

Table VI

Regression Results from Mediation Effects on Firm Profitability
Dependent Variable – Return on Sales

Independent Variable	Standardized Coefficient	F-statistic	Adjusted R^2	Sobel Test Statistic
NFMP	0.353***			
SU	0.038			
		9.175***	0.124	3.0537***
NFMP	0.306***			
CM	0.158*			
		10.094***	0.136	2.482**
NFMP	0.418***			
QI	-0.108			
		9.608***	0.132	3.270***
NFMP	0.346***			
SU	0.063			
CM	0.177*			
QI	-0.164			
		5.745***	0.146	N/A

Notes: n = 121 * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

SU = Setup time reduction
CM = Cellular manufacturing
QI = Quality improvement
NFMP = Non-financial manufacturing performance measures

The variance explained in the dependent variable by the system of equations (cf. Bouwens and Abernethy, 2000; Gerdin, 2005):
SU = 34.8%; CM = 22.2%; QI = 28.3%

Table VII

Structural Equation Model Results:
Standardized Direct, Indirect, and Total Effects for ROS

Hypothesis	Dependent Variable	Independent Variable	Direct Effects	Indirect Effects	Total Effects
H5a	ROS	SU	0.061	0.146***	0.207
H5b	ROS	CM	0.140	0.086**	0.226**
H5c	ROS	QI	-0.187	0.145***	-0.041

Notes: n = 121

Measurement models are estimated using maximum likelihood. Bootstrapping is required in AMOS to determine the statistical significance of indirect effects.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

SU = Setup time reduction
CM = Cellular manufacturing
QI = Quality improvement
ROS = Return on Sales

Endnotes

[1]NFMP measures related to waste were significantly related to JIT manufacturing practices in their study. This study includes two additional productivity measures that were not on the Fullerton and McWatters (2002) original instrument.

[2] One reason for contacting the same firms as in earlier studies was to evaluate possible changes in their implementation levels of JIT and non-financial performance measures. The results of that evaluation are described in another working paper.

[3] Items where error covariances are included in the models are very close either semantically or conceptually. These include shop floor problem-solving efforts and suggestion programs (SF1 and SF2 as shown in the Appendix), and performance measures of scrap and rework (NFMP 4 and NFMP 5) and throughput time and manufacturing cycle efficiency (NFMP 8 and NFMP 9).

[4] As additional robustness tests, the models were analyzed utilizing summed variables instead of the full latent model, and also generated using 250 maximum likelihood bootstrapped samples (Kline, 2005). The results for all testing were qualitatively similar. Bootstrapping is a resampling procedure that can compensate for small sample size and does not invoke assumptions about multivariate normality. Multiple subsamples are drawn with replacement and comparisons of the parameter values of the repeated samples are made to determine fit and parameter estimates. Small samples or non-normal distributions of variables can violate the assumptions of maximum likelihood estimation of SEM parameters, and both can inflate the chi-squared value, incorrectly rejecting the fit of the model (West et al., 1995).

[5] To further assure that mediation (rather than moderation) properly describes NFMP measurement's intervening role in the lean manufacturing/financial performance relationship, MLR tests of moderating effects were also run. These three models include as independent variables the three lean practices, the extent of NFMP measurement, and their interaction. (The independent variables were centered to dispel collinearity issues with interactive variables.) In untabulated results, none of the interactions were significantly related to ROS, suggesting that NFMP measurement does not moderate the relationship between lean initiatives and financial performance.

[6] The differences between a restricted model and the full structural model using nesting procedures were also examined (see Bentler and Chou, 1987; Bollen, 1989). The paths connected to NFMP measures were restricted to zero and compared to the model with all paths freely estimated. The difference in the two models' chi-squares was significant ($p < 0.001$), providing additional evidence of NFMP measurement's mediating effects.