Revisiting the Roots of JIT and LEAN Manufacturing

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This paper reports an application of the approach to knowledge generation in Operations Management, described by Swamidass (1991) that includes theory testing, theory revision based upon research, and testing of the revised theory. The method is applied to JIT – a body of knowledge that has been extensively researched and practiced broadly for over 30 years. In spite of substantial research on the topic of JIT, we found limited evidence that the approach to knowledge generation has been followed completely. While many studies of various aspects of JIT have been reported, we found very few that examine all of the core relationships originally proposed by Schonberger (1982) and none that simultaneously tested the entire set of specific relationships. Furthermore, we failed to observe in the literature, any revisions or updates to the original model that were evaluated against the full original model. Thus, significant gaps exist with respect to knowledge generation in the area of JIT. This study seeks to remedy those knowledge gaps.

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I. INTRODUCTION

Many companies around the world have implemented Just-in-Time (JIT) production management or associated practices such as ‘Lean’. Early proponents of JIT attempted to explain what JIT was, how it worked and how it affected the operational performance of firms (e.g. Hall, 1983; Hay, 1988; Schonberger, 1982). Since these early descriptions of JIT, many empirical studies have demonstrated that operational and financial performance improvements generally follow successful implementations of JIT principles and practices (e.g. Fullerton and McWatters, 2001; Fullerton, McWatters, and Fawson, 2003; Huson and Nanda, 1995; White, 1999).

Quality Management in its various forms (e.g. Total Quality Management (TQM), Six Sigma, etc.) represent another philosophy which has received the attention of researchers and practitioners. Early on, some considered TQM as a part of JIT (e.g. White, Pearson and Wilson, 1999), while others suggested that they were two separate philosophies that support each other (e.g. Flynn, Sakakibara, and Schroeder, 1995; Sriparavatsu and Gupta, 1997; Vuppalapati, Ahire, 1995). Ensuing research demonstrated that the two philosophies can support each other (e.g. Cua, McKone, and Schroeder, 2001; Lau, 2000). More recently, the practice of “Lean-Six Sigma” incorporates and integrates principles and practices of JIT/LEAN with those of TQM/Six Sigma (Evans and Lindsay, 2005).

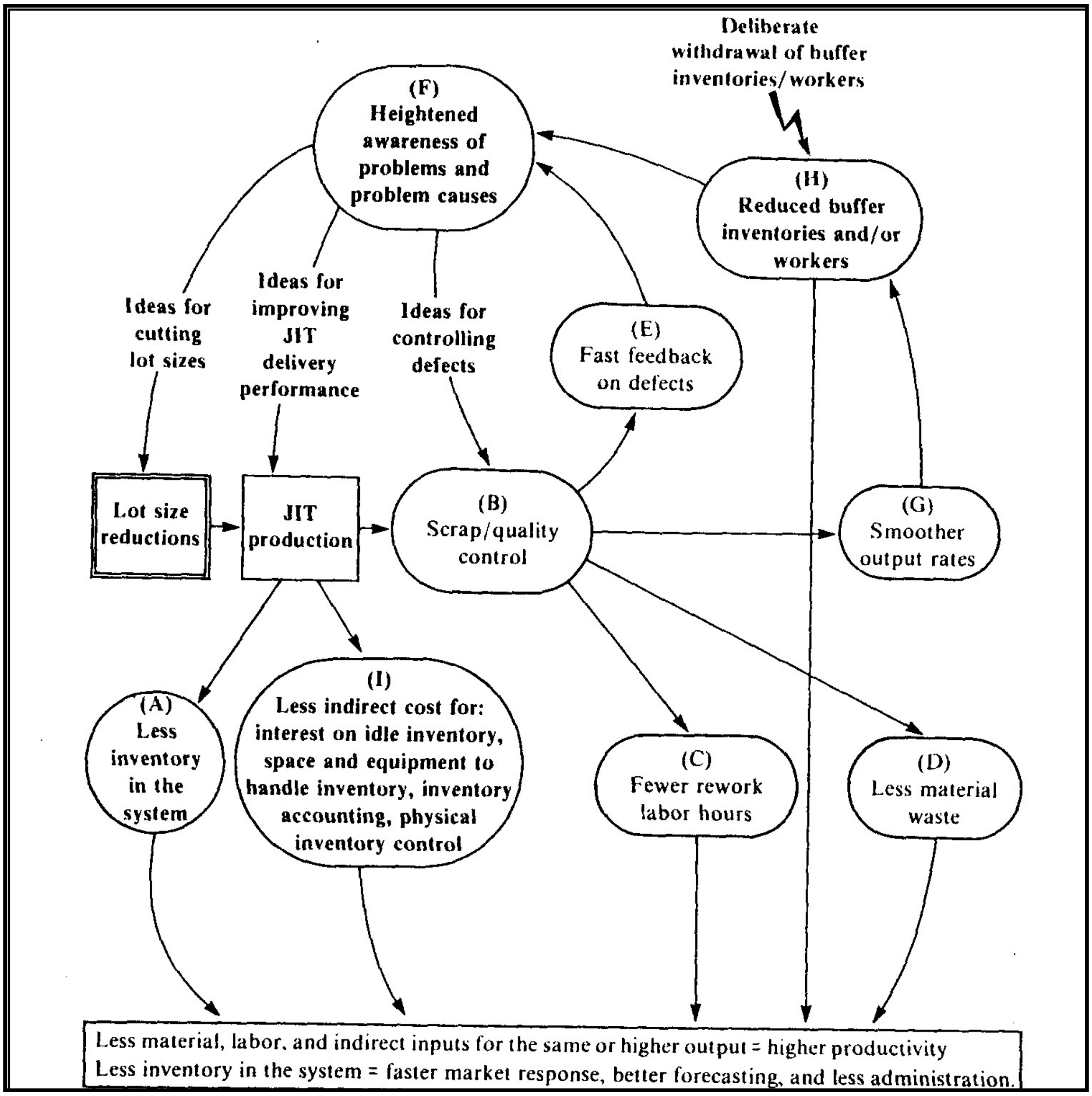
Although there are many studies about JIT practices, their inter-relationships, and the effects of JIT practices upon manufacturing performance, we were surprised when we failed to find a comprehensive empirical test of Schonberger’s (1982) original JIT model, including the core JIT practices and their effects upon manufacturing performance that also included the specific inter-relationships that he identified. Schonberger's (1982) model is of particular interest because it provided one of the first comprehensive conceptual descriptions of the practice of JIT. Furthermore, it described key aspects of JIT and the proposed relationships along with explanations of why those relationships were expected to exist – thus providing key components of a theory of JIT. The absence of a 'complete' test of Schonberger's theoretical model is significant for both practical and theoretical reasons.

On the practical side, not all implementations of advanced manufacturing practices (e.g. JIT, Lean, TQM, Six Sigma, etc.) have been successful (e.g. Dooley and Flor, 1998; Giffi, Roth, and Seal, 1990; Sohal, Ramsey, and Samson, 1993; Taylor and Wright, 2003). One plausible explanation for failed JIT implementations is an incomplete implementation of the highly inter-dependent JIT practices. Many of the benefits of JIT depend upon the synergies created when the whole program is implemented. Therefore, an inaccurate understanding of the inter-relatedness of the basic JIT practices could lead managers to mistakenly believe that a partial implementation of JIT could provide a full set of benefits.

The absence of a 'complete' test of Schonberger's (1982) model is even more significant from a theoretical perspective. Swamidass (1991) described the process of knowledge generation in Operations Management as necessarily including the development of a model (which Schonberger did), the testing of the model (which many studies have engaged in – but typically only in part), and the development of a revised model which is subsequently tested to verify its relative superiority to the original model (which apparently has not been done). While Schonberger (1982) gave us a conceptual model, most studies reported in the literature appear to have either analyzed specific sub-models (as opposed to the full model) or have evaluated implications derived from the model. We found very few, if any studies that actually attempted to empirically analyze the full set of relationships proposed by Schonberger (1982) – as a set of relationships. Thus, many studies have given us either a micro or macro view of JIT, but few if any have actually given us a holistic test of the relationships that were proposed. This is a crucial issue because one of the necessary aspects of knowledge development appears to have been overlooked in the literature. The problem is further compounded, because without a test of the full original model, there is no baseline for comparison when alternative or revised models are developed or proposed. Perhaps this is why we did not find – after more than a quarter century of study has been devoted to JIT – any 'revised' versions of the full Schonberger model evaluated in the literature. The absence of a full and simultaneous test of the relationships in Schonberger's (1982) original model or of any 'revised' Schonberger models in the presence of so much published research is a significant gap in the development of knowledge in the field of Operations Management.

Schonberger (1982) proposed a conceptual model (reproduced as Figure 1) that described the effects the JIT practices such as: setup time reduction, small lot size, pull production, quality circles and total quality management upon other JIT practices and upon manufacturing performance. Although this model provides useful insight for managers, we found no explicit tests of the full model in the literature. What we did find was numerous studies that tested parts of the JIT "model" or implications of the JIT "theory". The diagram provided by Schonberger (Figure 1), was not necessarily intended to be a formal representation of a theoretical model. Therefore, we have taken some liberty in developing a more formal model based upon our interpretation of not only Schonberger's original drawing, but more importantly, the numerous pages of discussion that he provided to explain his figure. Our interpretation of his model is represented by Figure 2 (Model A: Schonberger's original model) which appears later in this paper, following a discussion of the hypothesized relationships. The discussion of hypotheses for Model A is based upon Schonberger's original framework, and is supplemented by additional literature at times. We have intentionally kept that discussion short, as many readers are likely familiar with many of the relationships and the reasoning underlying them.

FIGURE 1.
SCHONBERGER'S (1982, P.26) JIT MODEL.



The objective of this paper is to report our formal test of Schonberger's (1982) JIT model and to compare the results of that analysis with those obtained from an updated(revised) version of Schonberger's (1982) model – an alternative model that is based upon research findings that have appeared in the years following. The updated model (Figure 3) is presented later in the paper, following the discussion of hypotheses. We developed it based upon the research reported in many other studies, each of which are important as each one has added to the knowledge base of JIT. Therefore our study both evaluates and builds upon Schonberger's original model by integrating past and present research.

II. LITERATURE

A large number of studies have evaluated the impact of JIT upon operational performance. A comprehensive review of them is not possible in this paper, therefore, we discuss a few of them as examples that are representative of the broader literature.

Huson and Nanda (1995) studied the effect of JIT implementation on accounting performance measures. The study was based on a survey of 55 U.S. companies that adopted JIT. They found that JIT was positively related to higher levels of performance such as: inventory turnover, earnings, and sales per employee.

Sakakibara, Flynn, and Schroeder, (1997) conducted an empirical study that tested the relationship between core JIT practices; infrastructure practices, manufacturing performance and competitive advantage. Their results indicated no significant relationship between the set of core JIT practices and manufacturing performance; however, they observed a significant relationship between the combination of the infrastructure practices with JIT practices, and manufacturing performance. Their study also noted a strong relation between the core JIT practices and infrastructure practices.

Nakamura, Sakakibara, and Schroeder, (1998) studied the effect of JIT and Quality Management on a sample of 40 plants in the U.S. The sample included plants which had adopted JIT and others which had not. The results showed a significant statistical relation between JIT implementation and performance measures such as: throughput time, conformance quality, down time and inventory to sales ratio.

White, Pearson, and Wilson, (1999) studied the JIT implementation in large and small US companies. The study was based upon the 10 management practices of JIT defined by White and Ruch (1990). This study found that large manufacturers had adopted more JIT practices than small manufacturers. On the other hand, both small and large manufacturers had a significant improvement in the performance due to the implementation of JIT. However, the effect of each JIT practice on the performance was not the same for both manufacturer sizes.

Fullerton and McWatters (2001) studied 95 U.S. firms who practiced JIT. They found that companies that had a more comprehensive implementation of JIT and quality management exhibited greater improvement in their performance than those who had a limited implementation. Fullerton, McWatters, and Fawson, (2003) found that JIT leads to higher profitability measured by return on assets, return on equity and cash flow margin.

Each of these studies evaluated the impact of JIT practices upon some type of performance and each found a positive relationship either directly or in combination with other factors upon operational and, or firm performance. However, for the most part, these studies and many other similar studies stopped short of a detailed analysis of the complete model that Schonberger (1982) originally proposed, including the inter-relationships among the JIT practices and how those inter-relationships then directly and indirectly affect operational performance. Thus the state of knowledge of JIT has been arrested: we do know that JIT can have a positive effect upon performance, but do the effects among JIT practices work exactly like Schonberger (1982) stated that they would? We could not find a clear answer to this question via a simultaneous test of all of the relationships in Schonberger's (1982) full model in the literature, even though we found many studies that partially addressed the question.

A substantial number of studies have also been reported in the literature which examine the relationship between JIT and TQM. Again, for the sake of brevity, we review a few of them which we take to be representative of the broader literature.

Vuppalapati and Ahire, (1995) suggested that there is a synergy effect between TQM and JIT. Moreover, they reasoned that JIT should be considered as a component of the TQM philosophy. They reasoned that both JIT and TQM should be implemented concurrently and should not be viewed as separate philosophies.

Flynn, Sakakibara, and Schroeder, (1995) reasoned that JIT and TQM are not only compatible, but that they actually support each other. They posited that TQM reduces process variance and rework which results in less need for work-in-process inventory (WIP) resulting in more effective implementation of JIT. They further reasoned that JIT supports TQM by reducing lot size and WIP, thereby making it easier and faster to find defects. Their analysis found support for the idea – although they did not directly test the reasoning stated above. In a more general analysis, they found that the combination of JIT & TQM practices resulted in better time-based and quality-based performance outcomes for manufacturers when compared to those who implemented only JIT or only TQM.

Sriparavastu and Gupta's (1997) empirical study found support for the hypothesis that companies which were implementing JIT and TQM should outperform those who were implementing neither JIT nor TQM. Their results showed that TQM companies exhibited better quality than JIT companies, while JIT companies had a better production performance than TQM companies.

Lau (2000) found that companies implementing both JIT and TQM outperformed those applying JIT only. Their analysis revealed a strong correlation between time-based performance and quality performance. However, compared with TQM companies, the JIT & TQM companies were slightly better in some performance measures. Additionally, JIT companies had better time-based performance and less quality performance than TQM companies. Finally, they found that companies which implemented neither TQM nor JIT had the lowest performance.

Cua, McKone, and Schroeder, (2001) found that TQM, Total Productive Maintenance (TPM) and JIT have a relatively different positive impact on each manufacturing performance measure (cost, quality, on-time delivery, and volume flexibility), but that these manufacturing practices interacted to positively support each other. They found also that the effect of those philosophies was enhanced by other practices such as: committed leadership, strategic planning, cross functional training, employee involvement and information feedback.

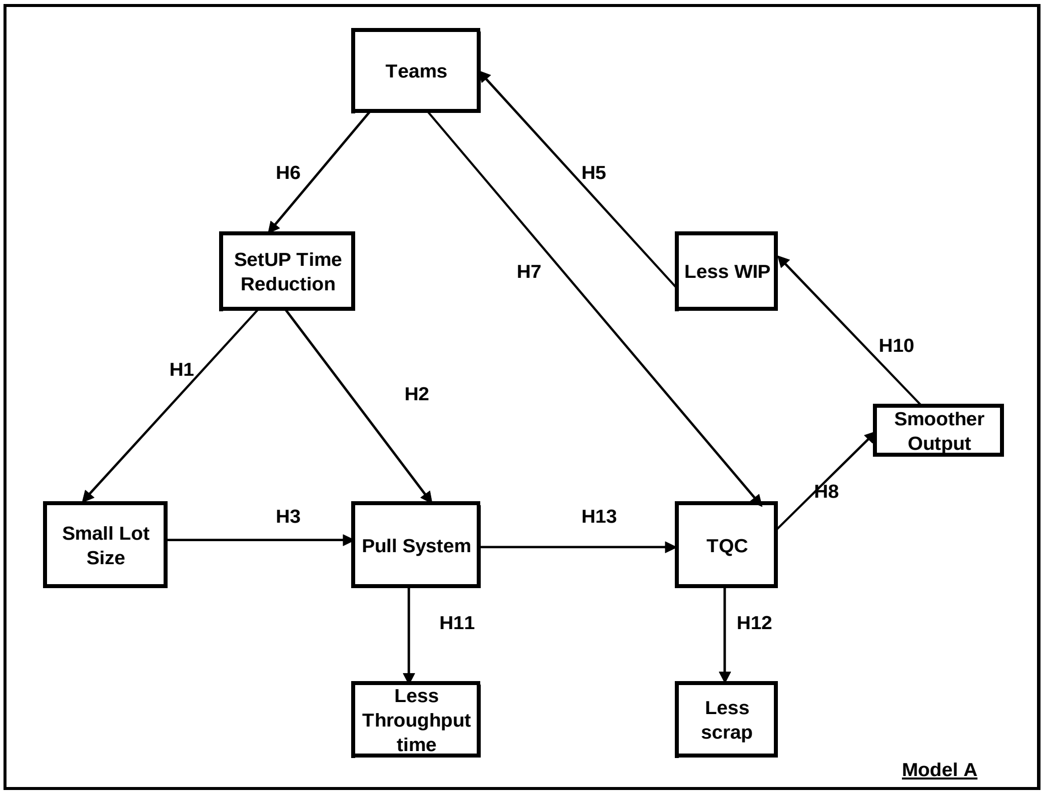
In summary, the research on the interaction of JIT and TQM practices seems to generally support the idea that JIT and TQM practices are supportive of one another and that used together, they tend to lead to better overall results than if used separately, or not at all. This is consistent with Schonberger's (1982) original model, which included aspects of both JIT and TQM practice. However, these studies (and most all other studies) have been focused primarily on the practices – performance linkage, not the more complex set of linkages between practices and their ensuing direct and indirect effects upon one another and upon operational performance. In short, these studies confirmed a general practices – performance relationship, but did not test the more specific relationships in the model or the entire model.

III. HYPOTHESES & MODELS

In this section, we provide hypotheses describing the relationships in Schonberger's (1982) model, as well as some additional relationships among specific JIT/TQM practices and specific manufacturing performance outcomes that have since been addressed in the literature. For matters of clarification, a brief summarization of important JIT and manufacturing related terms, based upon existing definitions found in the literature is provided in appendix A.

In the following paragraphs, we briefly review the rationale behind the relationships expressed in Schonberger's (1982) JIT model, as well as contributions that have been made in the literature following Schonberger's model, resulting in a set of hypotheses. While many of the resulting hypotheses are consistent with either Schonberger's original model, or a revised model, some are unique to either the original or a revised perspective. The hypotheses that are consistent with Schonberger's (1982) original framework are shown in Model A (Figure 2). Those consistent with a revised version of Schonberger's framework are shown in Model B (Figure 3). This approach was used, since both models share many of the same hypotheses; however, there are significant differences, which are discussed later.

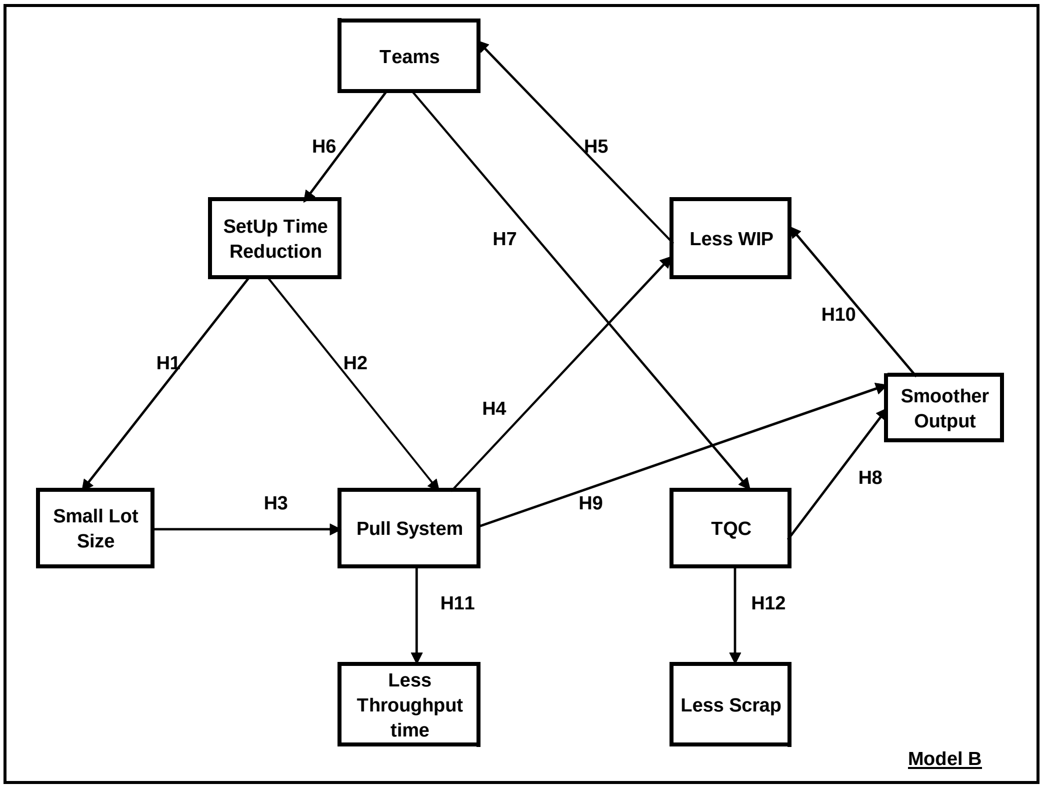
FIGURE 2.
MODEL A: SCHONBERGER'S ORIGINAL MODEL.



3.1 Hypotheses

Setup time can be classified into two categories: internal and external setup. Internal setups are those tasks that take place when the machine is stopped (i.e. not producing product). External setups are those tasks that can take place while the machine is running (Hopp, 1996). The reduction of setup time (and its associated costs) focuses on decreasing the internal setup time and, or converting internal setup into external setup because internal setup affects the production rate and throughput time. Amongst others, Shingo (1985) suggested different techniques for the reduction of setup time. According to the Economic Order Quantity model, which arises out of inventory theory, the reduction of the setup time, while the inventory holding cost remains unchanged, will result in a smaller economic lot size (Schonberger, 1982, Shingo, 1985). While a small lot size may be possible regardless of the

FIGURE 3.
MODEL B: REVISED MODEL.



setup time, it is not economical except with shorter setup time. Therefore, a manufacturer who wants to reduce the lot size will need to reduce the setup time first in order to do so cost effectively.

H1: Reducing setup time will be associated with small lot size production.

Relatively short setup times facilitate the implementation of a pull system for production (Schonberger, 1982). A long setup time will result in slow response to orders from downstream (Nicholas, 1998); however, a pull-system of production operates on the premise of fast response to downstream demand. Consequently, as setup time is reduced, pull system production is facilitated.

H2: Reducing setup time will be associated with the use of a pull production system. Small lot size production is essential for a pull

system because large lots will make a pull system ineffective and, or inefficient. Production in small lot sizes facilitates reduced WIP inventories as well as faster response to demand. With large lot size production, lead times generally increase in order to respond to the downstream requirements (Hopp and Spearman, 1996). Schonberger (1982) suggested that cutting lot size is the trigger for the chain of JIT benefits. Small lot size is necessary for implementing a pull production system.

H3: The greater the degree of small lot size production, the greater the degree of pull production.

One of the main differences between push and pull systems is the amount of WIP that can exist in the system. In a push system, each workstation follows the production schedule regardless of the real requirements (demand) at the next stage of production. That can lead to high WIP whenever planned production exceeds the demand rate. In a pull system, each workstation engages in production only when signaled by downstream demand. Furthermore, the amount of WIP between workstations is limited by the number of kanbans between workstations. Therefore, in a push system, forecasts in excess of demand will increase WIP and variation in demand will exacerbate the problem. In a pull system, WIP is controlled more directly by both stopping production when demand falls and through the use of the minimally necessary number of kanbans (Hopp and Spearman, 1996; Schroeder, 1993). Among others, White, Pearson, and Wilson, (1999) observed that pull systems in production were associated with reduced inventories in large firms.

H4: The greater the degree of implementation of a pull system, the greater the decrease in WIP.

Some authors have argued that the secret of the pull system is that it limits WIP (e.g. Hopp and Spearman, 1996; Spearman, Woodruff, and Hopp, 1990; Spearman and Zazanis, 1992). A primary function of WIP inventory is to act as a buffer between stages of production in order to give a degree of independence to each stage of production and to decrease the adverse effects of variability in production and demand upon a production system. Variability in production systems can occur due to natural reasons or mistakes in operation, maintenance, and quality. Reducing WIP makes problems more observable and thereby facilitates their identification and ultimately, their causes which furthers their resolution (Conway, 1988; Hall, 1983; Ou and Jiang, 1997). Thus, reduction of WIP increases the awareness of and motivation to solve problems, which, when accomplished, results in a more effective production system (Schonberger, 1982).

H5: Lower levels of WIP will be associated with the presence of quality improvement teams (circles).

The use of team-based quality problem solving groups has been given many names and definitions. However, the basic idea of a team or group of workers that comes together (whether formally appointed or informally organized) to identify and resolve production related problems is an important part of Schonberger’s (1982) model. His conceptualization of these teams and their activities was not strictly limited to the problems related to product quality but also included issues of efficiency, cost, equipment, safety, process control and work improvement in general (Ross and Ross, 1982; Schonberger, 1982, 1983). Schonberger (1982) recognized that in a JIT system, workers and management would identify a wide variety of opportunities for improvement and that many of these would necessarily be focused on reducing setup time. The involvement of workers and manufacturing technicians in quality teams should increase the sources of ideas for improvement and facilitate reduction of setup time (Hall, 1983; Maskell, 2001; Schonberger, 1982; Schroeder, 1993; Shingo, 1985).

H6: The greater the usage of quality teams (circles) for operational improvements, the greater the reduction in setup times.

Employees’ involvement in solving quality problems is an essential part of both JIT and TQM (Deming, 1986; Flynn, Sakakibara, and Schroeder, 1995; Schonberger, 1982). White, Pearson, and Wilson, (1999) found some evidence that the use of quality teams was associated with higher levels of internal quality in small firms. Quality improvements are often accomplished through the implementation of teams or 'quality circles'. One of the key elements team-based problems solving is the need for accurate and timely data. Statistical process control is a means of monitoring processes and gathering data that can be used by quality teams to identify the occurrence of quality related problems. Therefore, quality circles or teams are expected to encourage and facilitate the implementation and continuing operation of Statistical Process Control (SPC).

H7: The greater the use of quality teams (circles), the greater the implementation and use of SPC techniques in production processes.

A smoothed production system is a production system with a stable rate of output. A stable rate of output has many sources, but it will have less irregularity: less variability in demand, less unscheduled downtime, etc. SPC methods help identify potential problems that contribute to variability in output by monitoring processes for early signs of problems. As potential problems are identified and their causes are removed from the production system, their re-occurrence becomes much less likely, thereby increasing the dependability and stability of the production process. In this way, the identification and elimination of sources of variability in the production process eventually leads to a smoother output (Flynn, 1995). Therefore, the use of SPC techniques contributes to and facilitates smoothing the output of a production process.

H8: The use of SPC techniques will be associated with smooth production rates.

Ou and Jiang (1997) noted that a uniform production rate is 'characteristic element' of JIT or pull-system based production while Schneiderjans and Olson (1999) stated that kanban production control (often described as a pull system) was designed for a production environment that has uniform, level demand. A pull system of production control leads to smoother output because it decreases the variability in the system and therefore, less inventory is needed to buffer for uncertainty in demand and flow. In a study designed to identify measures of various aspects of JIT, Sakakibara, Flynn, and Schroeder, (1993) observed that daily schedule adherence (a surrogate for a level/smooth production system) was strongly correlated with practices related to a pull system. Therefore, we hypothesize that,

H9: The more a firm implements a pull system, the greater the smoothness of the production system and its level of output.

Production systems that have smoothed demand and output rates will exhibit less variability in their behavior. All other things being equal, lower levels of variability in the production system will result in a decreased need for inventory to buffer the uncertainty in the system. Furthermore, WIP inventory generally buffers for differences in production rates from one stage of production to the next; however, with pull production implemented, the rate of production from one stage to the next can be balanced by removing the need for inventory to buffer between stages of production, other than that necessary for the operations of kanbans (Hopp and Spearman, 1996; Schonberger, 1983). Therefore,

H10: Smoother output leads to less WIP

Schonberger (1982) suggested that Pull production leads to faster market response. Later, White, Pearson, and Wilson, (1999) found that pull production resulted in less throughput time for large manufacturers. Numerous other studies have made similar observations. Therefore,

H11: the greater the use of pull system, the lower throughput time.

Schonberger (1982) reasoned that the use of quality control methods and techniques such as SPC results in measurable quality improvement in scrap and rework. Numerous studies in both the areas of JIT and TQM have made similar arguments and often found results to support this line of reasoning (e.g. Lua, 2000; Sriparavastu and Gupta, 1997).

H12: Statistical process control leads to less scrap and rework.

Schonberger (1982) suggested that JIT supports process control. Operating a system with low buffer inventory, small lot sizes, with pull control will reveal problems and SPC methods are able to detect them rapidly. Thus, Schonberger reasoned that the existence of a pull-system for production control would encourage the use of SPC methods. Therefore, based upon Schonberger's original model, the following is hypothesized:

H13: The more that pull-system production control is used by a manufacturer, the more that the manufacturer will also utilize statistical process control.

3.2 Models

Two models are considered, which we label as models "A" and "B". As previously stated, Model A was derived from Schonberger's (1982) original framework. Model B is a revised version of Schonberger's original framework, based upon more recent research findings. The differences between the two models are: model "B" includes hypotheses H4 and H9 and does not include hypothesis H13. Models A and B are shown below in Figures 2 and 3, respectively.

Because various aspects of Schonberger's (1982) model have been supported in prior studies, it is not unreasonable to expect that many of the hypothesized relationships in both models A and B would be supported in this study. Similarly, it is also reasonable to expect the overall model fit to be acceptable for both models. However, because this analysis differs from prior analyses, results in this study may vary from those in the past. First, unlike more prior studies, this study will evaluate the entire set of relationships simultaneously, including both direct and indirect effects. The form of analysis conducted in the present study also allows for feedback loops in effects, which were not possible to assess using the correlation or regression-based analyses used in most prior studies. Therefore, the analysis conducted in this study has substantial advantages over prior studies in that it should be expected to more accurately estimate individual parameter estimates. Finally, this study provides and evaluates the original framework and an alternative model – allowing for a holistic test of the original versus a revised conceptual framework.

IV. METHODOLOGY

4.1 Data

The data used in this paper were gathered as part of prior research project, therefore this study is performing a secondary analysis of data. The data were originally gathered from 164 manufacturing facilities across three broad industrial groups, within five countries as part of the World Class Manufacturing research project (e.g. Flynn, Sakakibara, and Schroeder, 1995; Sakakibara, Flynn, Schroeder, and Morris, 1997). To preserve independence among responding facilities, no more than one plant from the same organization was included in the study. All plants included in the study had more than 100 employees and the response rate for participation in the study was 66%. A description of the sample is presented in Tables 1 and 2. Survey questions were initially written in English, translated into the other languages and then back-translated to English to ensure the translation quality.

4.2 Measures: Reliability and Validity

Appropriate (content valid) measures were identified for all of the constructs (variables) that are indicated in the hypotheses. The measurement of each construct utilized a single objective variable when one was available in order to maximize reliability and validity, since objective measures are generally considered much more reliable and valid. When objective measures were not available, an attempt was made (consistent with prior research studies) to utilize multiple subjective measures of each construct. Variables that were measured subjectively utilized five-point Likert-type measurement scales. Questions that were reverse-worded in the original questionnaire were re-coded prior to analysis. For most constructs, several subjective measures were available (typically three to seven); however, upon close scrutiny, our assessments of reliability for each construct that was measured using multiple subjective measures tended to vary by country. Careful and detailed analyses revealed that in general, the use of two variables (for each construct) provided maximum consistency in reliability measurements across subsets (countries and industries). This resulted in two subjective variables being used to measure each of the latent constructs except throughput time and conformance quality, which were measured using one objective variable each. Descriptive statistics of the variables are presented in Table 3.

TABLE 1.
DISTRIBUTION OF SAMPLE BY COUNTRY AND INDUSTRY.

	Germany	Italy	Japan	UK	USA	Total
Electronics	9	11	17	7	10	54
Machinery	11	13	14	7	10	55
Transportation	13	10	15	7	10	55
	33	34	46	21	30	164

Reliability for the subjective measures was assessed in two ways: using Cronbach'salpha and by inspecting the size and significance of loadings of the variables on their factors when performing a confirmatory factor analyses (See Table 4 for details). All of the measures had alpha values greater than .60, and the majority of the measures have values greater than .70, which is preferable in theory testing situations like this one (Nunnally, 1978). However, Nunnally's cut-off values are based upon the assumption that scales are typically constructed from several variables. Because alpha values decrease with the use of fewer variables (the present study used the minimum number possible: 2 variables per measure) alpha values in the .60 to .70 range should not cause undue concern. However, as a further check on reliability a confirmatory analysis conducted to further assess the reliability and validity of measures utilized in this study. It was not possible to test a single measurement model because each construct had only two observed variables. Therefore, at least two measurement models were always tested together. This resulted in seven measurement models being tested with the results summarize in Table 4. Each of the observed variables in each construct was statistically significant ($p \leq .001$). The regression weights (factor loadings) were between 0.607 and 0.951, which are considered acceptable (Hair, Tatham, Anderson, Babin, and Black, 2005). Once estimated in the factor analysis, the factor loadings were fixed during the analysis of the structural model testing, which is consistent with the two step process

TABLE 2.
DESCRIPTIVE DATA FOR THE SAMPLE.

		Country					Industry		
Characteristic	All Plants	Germany	Italy	Japan	UK	USA	E*	M*	T*
Number of salaried Employees	430	311	385	620	598	174	598	197	487
Number of hourly Employees	758	704	292	1276	951	364	509	492	1277
Year plant built	1960	1955	1961	1960	1955	1966	1965	1956	1958
Equipment age									
Less than 2 years old	15%	18%	16%	13%	14%	13%	20%	11%	14%
3-5 Years Old	30%	24%	32%	30%	30%	36%	40%	24%	26%
6-10 Years Old	26%	32%	24%	27%	25%	21%	28%	25%	26%
11-20 Years Old	20%	24%	21%	17%	23%	17%	11%	28%	20%
Over 20 Years Old	11%	10%	7%	12%	9%	13%	3%	14%	15%
Manufacturing Costs									
Direct Labor (% of manufacturing costs)	16%	22%	23%	12%	12%	11%	15%	16%	17%
Materials (% of manufacturing costs)	58%	52%	60%	60%	59%	60%	58%	60%	57%
Overhead (% of manufacturing costs)	22%	26%	17%	16%	29%	30%	23%	21%	21%
Production Processes									
One of a kind	13%	14%	13%	15%	8%	10%	11%	22%	6%
Small Batch	29%	34%	39%	16%	45%	20%	30%	33%	23%
Large Batch	16%	25%	20%	6%	13%	20%	14%	11%	23%
Repetitive / semi-continuous	28%	11%	24%	34%	32%	40%	30%	28%	26%
Continuous	14%	15%	4%	28%	1%	11%	15%	5%	22%

*E: Electronics, M: Machinery, T: Transportation

TABLE 3.
DESCRIPTIVE STATISTICS.

Construct	Measures	N	Min	Max	Mean	Std Dev
Teams	Our plant forms teams to solve problems.	163	1.92	4.83	3.68	0.57
	Problem solving teams have helped improve manufacturing processes at this plant.	163	1.92	4.75	3.63	0.49
Less WIP	We have a small amount of work-in-process inventory, compared to our industry.	163	2.00	4.57	3.33	0.46
	We have low work-in-process inventory on the shop floor.	163	2.00	4.75	3.44	0.54
Setup Time Reduction	We are aggressively working to lower setup times in our plant.	163	2.00	4.86	3.69	0.60
	Our crews practice setups to reduce the time required.	163	1.33	4.86	2.98	0.82
Smoother Output	We usually meet the production schedule each day.	163	2.00	4.86	3.63	0.57
	We usually complete our daily schedule as planned.	163	2.25	4.71	3.66	0.55
SPC: Statistical Process Control	We make extensive use of statistical techniques to reduce variance in processes.	163	1.40	4.83	3.43	0.72
	We monitor our processes using statistical process control	163	1.50	4.83	3.31	0.62
Pull System	We use kanban squares, containers or signals for production control.	163	1.14	5.00	3.07	0.78
	Our suppliers deliver to us in kanban containers, without the use of separate packaging.	163	1.14	4.57	2.59	0.62
Small Lot size Production	We are aggressively working to lower lot sizes in our plant.	163	1.25	4.86	3.04	0.64
	We emphasize small lot sizes to increase manufacturing flexibility.	163	2.00	4.86	3.36	0.57
Less Scrap: Quality	What is the percentage of internal scrap and rework?	137	0.00	35.00	5.00	6.46
Throughput Time	What is the average lead time from the receipt of an order until it is shipped (in days)?	128	0.02	1095.00	63.02	115.56

recommended by Anderson and Gerbing (1988).

Finally, we note our efforts to assure proper content validity. We defined out constructs based upon the definitions found in the literature. Then we used measures that have been previously used in the literature for those defined constructs. While not formally assessing the content validity of each construct, our approach follows the pattern established in prior research.

V. ANALYSES

Structural Equation Modeling (SEM) was used to test the two models because it allows the assessment of the overall model fit, which is important in evaluating the relative value of the full theoretical model. This form of analysis also simultaneously estimates of all paths in the model, including feedback loops. The application of SEM analysis was particularly appropriate, given the nature of the proposed relationships as of the 'theory-testing' approach used herein. A two step approach (Anderson and Gerbing, 1988; Hair, Tatham, Anderson, Babin and Black, 2005) was applied wherein the measurement models were estimated and evaluated first. When it was determined that the measurement models were acceptable, their parameters were fixed while the entire structure model was estimated. SEM was conducted using AMOS software, which is one of several commercially available SEM software packages (Arbuckle & Wothke, 1999).

5.1 Structural Model Fit

To the extent that the model accurately describes practice, we would expect that all of the hypothesized relationships would be significant and that the overall model fit would also indicate good model fit. The results of the structural model analyses are presented in Figures 4 and 5 for models "A" and "B" respectively.

5.2 Results

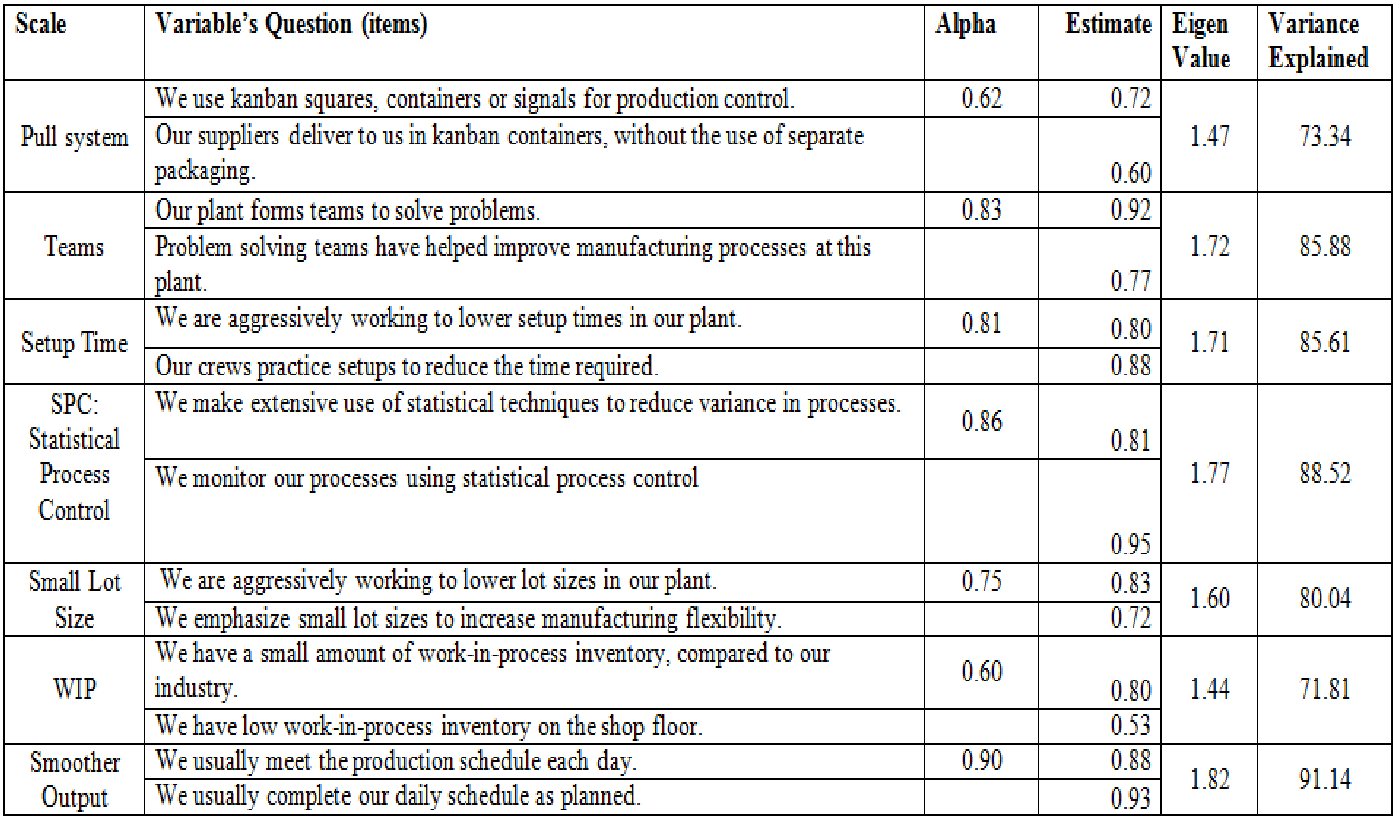
Model A (based upon Schonberger's original model) had a chi-square to degrees of freedom ratio of 1.38, which is statistically significant at 0.003, suggesting that the model is not a good fit to the data (Carmines and McIver, 1981; Fornell, 1983). The Root Mean Square Error of Approximation (RMSEA) was significant at 0.05, which is right at the cut-off of generally acceptable model fit (Browne and Cudeck, 1993). Finally, the Tucker-Lewis Index (TLI) indicated that the model was acceptable at 0.95 (0.90 is the generally accepted cut-off). In contrast, the chi-square test for model B was not statistically significant, while the RMSEA and TLI statistics were significant in the direction of model acceptance (Bentler and Bonnet, 1980). The pattern of marginally acceptable fit for model A and better fit for Model B was also observed with other measures of fit, such as the Incremental Fit Index (IFI), the Normed Fit Index (NFI) and the Relative Fit Index (RFI). Results are summarized in Table 5 (below). These results indicate that while Model A had a somewhat questionable, but marginally acceptable model fit, model B was a better fit to the data.

Next, we examined hypotheses in each model. All of the hypothesized relationships in model A were statistically significant at the 0.05 level or better, with the exception of the Pull-system – SPC hypothesis. Model B, did not include the Pull system – SPC hypothesis, but it did include two additional relationships: Pull system – Smoother output and Pull system – WIP, both of which were significant, as well the rest of the hypothesized relationships in model B. We do note; however, that parameter estimate for the Less WIP – Teams hypothesis decreased slightly in value, just enough to drop its level of significance to the 0.10 level.

VI. DISCUSSION

In general, the results of the analyses of the

TABLE 4.
SUMMARY OF RELIABILITY ANALYSES.



Scale	Variable's Question (items)	Alpha	Estimate	Eigen Value	Variance Explained
Pull system	We use kanban squares, containers or signals for production control.	0.62	0.72	1.47	73.34
	Our suppliers deliver to us in kanban containers, without the use of separate packaging.		0.60		
Teams	Our plant forms teams to solve problems.	0.83	0.92	1.72	85.88
	Problem solving teams have helped improve manufacturing processes at this plant.		0.77		
Setup Time	We are aggressively working to lower setup times in our plant.	0.81	0.80	1.71	85.61
	Our crews practice setups to reduce the time required.		0.88		
SPC: Statistical Process Control	We make extensive use of statistical techniques to reduce variance in processes.	0.86	0.81	1.77	88.52
	We monitor our processes using statistical process control		0.95		
Small Lot Size	We are aggressively working to lower lot sizes in our plant.	0.75	0.83	1.60	80.04
	We emphasize small lot sizes to increase manufacturing flexibility.		0.72		
WIP	We have a small amount of work-in-process inventory, compared to our industry.	0.60	0.80	1.44	71.81
	We have low work-in-process inventory on the shop floor.		0.53		
Smoother Output	We usually meet the production schedule each day.	0.90	0.88	1.82	91.14
	We usually complete our daily schedule as planned.		0.93		

TABLE 5.
ANALYSIS OF MODEL FIT.

	MODELS	
	A	B
Chi-square level of significance	0.003	0.085
RMSEA	0.048	0.033
TLI	0.949	0.977

two models exhibit more similarities than differences – but both are important. Both sets of results suggest that either model could be accepted, but the results for model B were more compelling. Both analyses agree that quality-improvement oriented teams support setup time reduction and SPC. Both analyses agree that setup reduction supports small lot sizes and a pull system. Both also agree that a pull system supports shorter throughput times and SPC is consistent with less scrap (waste). In addition, both analyses support the notion of a virtuous cycle wherein quality teams support quality control, which contributes to smoother output, which contributes to lower WIP, which, in turn, supports quality teams' efforts to find and fix production problems.

However, a significant difference emerges in how the two models suggest that the pull system affects the virtuous cycle of quality

FIGURE 4.
MODEL A: ANALYSIS OF SCHONBERGER'S MODEL

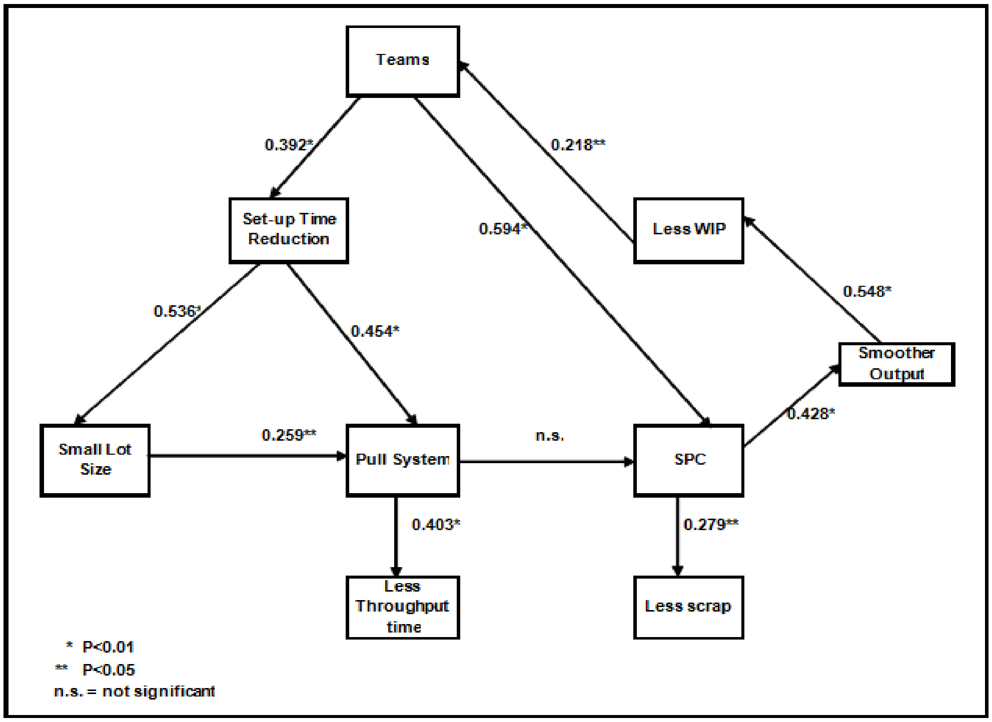
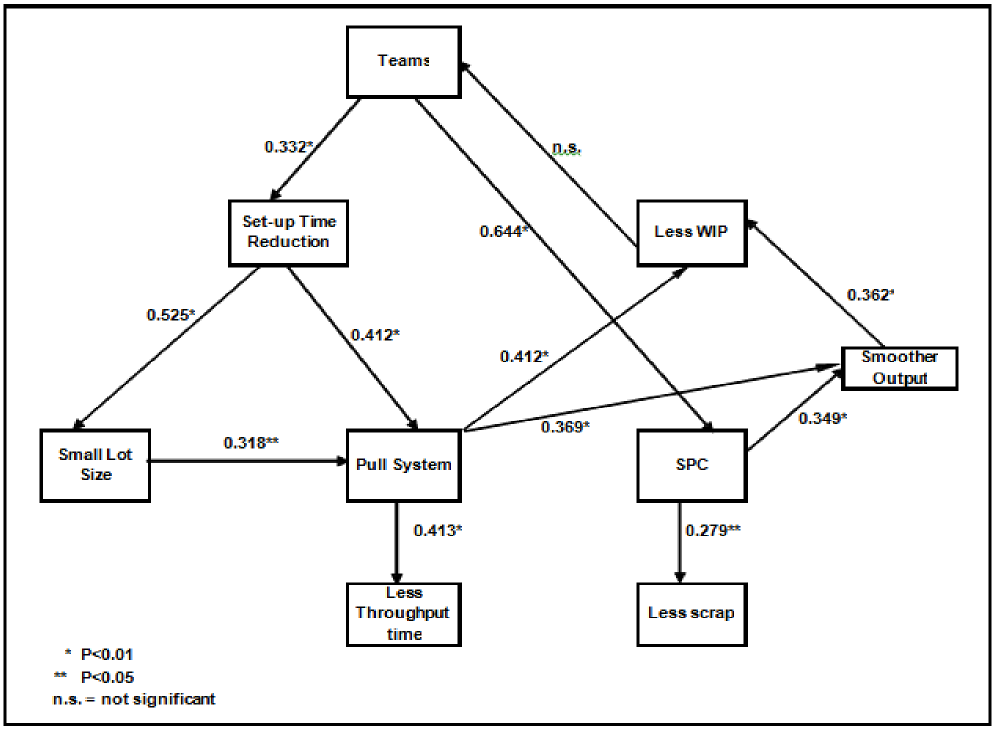


FIGURE 5.
MODEL B: ANALYSIS OF THE 'REVISED' SCHONBERGER MODEL.



teams—quality control—smoother output—less WIP—and back to quality teams. Schonberger's original model, which was not as well supported as the revised model, particularly in this second 'cycle', suggests that the effect of the pull system flows fully through the quality control activities. However, model B, which was better supported in the analyses, indicated that the operation of a pull system affects the cycle noted above, not through process control, but through direct effects upon both smoother output and less WIP. To examine this further, we estimated another model B with the addition of a path between pull system and SPC. The overall model significance was not improved (in fact, it was marginally lower) and the additional path was not significant. This post hoc analysis suggests that Schonberger's original model, while insightful, needs to be updated to reflect a more accurate description of how the application of a pull system affects quality, smoothed production, WIP, and indirectly, problem solving teams.

Consistent with Schonberger's general arguments and results from multiple studies cited earlier in this paper, the results of our analyses indicate that there is a relationship between JIT and TQM concepts and practices. The results of our analysis are somewhat consistent with Flynn, Sakakibara, and Schroeder, (1995) who suggested that TQM supports JIT through the reduction of variance. However our findings differ from Flynn, Sakakibara, and Schroeder, (1995) who suggested that JIT supports TQM through the quality improvement because of the small lot size. Our findings in this matter are more consistent with Inman, Bhaskaran, and Blumenfeld, (1997) who reasoned that decreasing the lot size without any other effort to improve quality will not result in less scrap.

As with all studies, this one is not without potential weaknesses. The data used in this study were gathered from a relatively small number of industries and countries. Therefore caution should be applied when interpreting the results of this study. The data were cross-sectional, and therefore, any causal interpretations must be based upon theory and interpreted with caution as well. Time series data is necessary to ultimately confirm the causality which has been discussed and inferred herein. Common methods bias might be a concern with this data, however, the data were gathered from key informants based upon their roles within the organization and therefore, this threat was likely negligible at worst. Furthermore, the confirmatory factor analysis failed to identify a single factor upon which all of the factors loaded, providing additional evidence suggesting that common methods bias was probably not an issue herein.

VII. MANAGERIAL IMPLICATIONS

JIT practices support each other, much as Schonberger (1982) suggested, but with some important modifications. Because JIT practices are to a significant extent, inter-related and self-reinforcing, the effects of JIT practices upon manufacturing performance should not be reduced to one single practice. This study supports Schonberger's explanation that the benefits of JIT are not fully noticed until all the practices are applied. For example, consistent with Ohno (1991), this study shows that applying pull system (or kanban type) practices without the rest of the JIT practices will not result in nearly as much performance enhancement as if the entire set of JIT practices is implemented. This study also supports the notion that JIT practices and results are self-reinforcing. Additionally, it supports the idea that JIT and TQM practices are co-dependent, meaning that they support each other to some degree, although the exact nature of the causes and effects were not as clearly described in Schonberger's original model as they are in practice today.

Managers implementing JIT and TQM should consider how the specific practices interact with each other when preparing an implementation plan. This study helps clarify precisely how the JIT practices interact. First, one should not attempt to implement all practices simultaneously, as improvement in some precedes and supports improvement in others. Thus, the implementation of the various practices should be thoughtfully staged, so as to maximize success in each wave of implementation. For example, the reduction of setup time should precede the reduction of lot size and both should precede the implementation of pull type control of production (e.g. kanban type approaches). However, it is important to realize that improvements in some practices do eventually feed-back and support further improvements, so delaying the application of a pull-system too long in a JIT implantation might also have adverse consequences of delayed or stalled improvement opportunities.

JIT leads to improvement primarily in time-based production performance outcomes such as cycle time and lead time while TQM and related quality practices contribute primarily to improved product and process quality, system stability and reduced variability. However, in addition to the primary effects of JIT and TQM related practices as noted above, they do tend to reinforce each other to some degree, as prior research suggests and as the revised model indicates. Finally, we note that the implementation of JIT and SPC concurrently will enhance the results on both the time-based performance and quality. Also, the concurrent application will be easier because both of them will help having a smoother output and less WIP which will then increase the awareness and motive to solve the problems that affects production and quality. The results of this study help clarify more precisely than prior studies, how the JIT and TQM practices actually interact and re-enforced and support one another.

VIII. CONCLUSION

This research reported an empirically-based structural equations modeling analysis of Schonberger's (1982) JIT model and as well an updated version of the same and found that the updated model is a more accurate representation of the inter-relationships among JIT practices and manufacturing performance. In addition, the study found that while some of the mechanisms within the JIT framework operate as Schonberger (1982) proposed, some of them operate in a manner that is somewhat contrary to what was originally proposed. The study provided results that have a reasonable degree of generalizabilty, because it used data from multiple industries and countries. While the essence of Schonberger's original model was marginally supported – depending upon the measure of model fit that was considered, the revised model exhibited consistently better model fit. The revised model appeared to more accurately describe practice of JIT and TQM related practices espoused by Schonberger (1982). In addition, the revised model more clearly demonstrated the inter-relationships among JIT practices and the multiple feedback loops inherent in the practice of JIT principles.

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X. Appendix A. Definitions of Key Terms.

Definition	Additional Supporting Literature
Setup time is defined as the downtime of the operation to change from one part or product to another.	(Hall, 1987)
The *lot size* is the quantity of items produced in a particular production run	(Nicholas, 1998)
Work In Process (WIP) is the inventory after the first step in manufacturing and before the last. This does not include the raw material and finished goods inventory.	(Conway, 1988)
Pull system, also called Kanban system, is a control system where the flow of material and pace of production are controlled by the operators according to the real need.	(Hopp and Spearman, 1996; Meredith, 1999)
A Quality Circle, or quality control circle, is a small group of employees that are doing related work and who meet regularly to identify, and analyze and solve production quality and production problems to improve general operations.	(Ross and Ross, 1982)
Statistical Process Control (SPC) is an approach to improving the quality of goods and services.	(Flynn, 1995)
Smoother output of a production system means that the output of the system is more stable with less irregularity.	(Schonberger, 1982)
Throughput time is sometimes called cycle time, flow time, and manufacturing lead time. In this paper we define Plant Throughput Time as the total time necessary to procure raw materials, to transform raw material into finished goods, and to ship the goods to customers.	(Hall, 1997; Schroeder, 1993)