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# Collaborative Product Design and Development: Experience Learned from Just-in-Time Manufacturing System

**(Full Paper Submission)**

Mohammad Z. Meybodi
Indiana University Kokomo
mmeybodi@iuk.edu

## ABSTRACT

This article aims to establish potential relationship between Just-in-Time (JIT) manufacturing system and collaborative product design and development (CPDD) method. Analysis and comparison of several critical elements show high degree of resemblances between the two elements. A number of hypotheses regarding similarities between elements of the two methods were developed and tested. Survey data from a sample of manufacturing organizations strongly supports the hypotheses regarding similarities between the two methods. Statistical results also indicate compared with conventional companies, by utilizing CPDD, JIT manufacturing organizations are able to design and develop new products with much better performance measures.

KEY WORDS: Collaborative Product Desing and Development, Just-in-Time Manufacturing

## INTRODUCTION

In a global market, innovation and speedy new product development is crucial for companies to gain competitive advantage. Creating new product ideas that are consistent with organizational strategy and moving these ideas through the stages of design, development, testing, and deployment has been the trade mark of successful world class organizations (Jacobs and Chase, 2017; Ferioli et al. 2010; Roulet et al. 2010; Towner, 1994). Introducing new products to the market early has several strategic and operational advantages. It often means premium prices, building name recognition, controlling a large market share, and enjoying the bottom line profits. Better competitive position in the market makes it also difficult for competition to enter the market (Blackburn, 1991; Cooper and Kleinschmidt, 1994; Lofstrand, 2010; Zahra and Ellor, 1993). Despite its well-known strategic role, for large number of manufacturing organizations innovation, design, and successful management of new product development has often been a major challenge. Long development time, prohibitive development and manufacturing costs, and questionable quality have been the common result for many of these organizations. The primary factor contributing to such unsuccessful result is perhaps the use conventional sequential method by these organizations (Blackburn, 1991; Morgan and Liker, 2006). However, manufacturing literature for the past three decades clearly shows that through their JIT manufacturing practices, some world class organizations such as Toyota have dominated competition not only in the area of manufacturing but also in the area of innovation, design, development, and quick commercialization of new technologies (Marisa et al. 2008; Blackburn, 1991; Clark and Fujimoto, 1991; Ulrich and Eppinger, 2004; Michael, 2008; Unger and Eppinger 2009). Instead of traditional sequential approach, a successful strategy employed by these world class organizations is collaborative product design and development (CPDD) method. The focus of this article is to understand such contrast between the two types of organizations. The question of interest in this article is: Are there relationships between success in JIT manufacturing practices and success in CPDD?

## LITERATURE REVIEW

JIT has been a great force in the world of manufacturing since mid 1980's. Some of the main benefits of a JIT such as lower inventory, quicker delivery, and lower cost have been well documented (Cook and Rogowski, 1996; Hobbs, 1994; Payne, 1993; Temponi and Pandya, 1995; Deshpande and Golhar, 1995; Billesbach, 1991; Handfield, 1993; Lawrence and Hottenstein, 1995; Golhar, Stamm, and Smith, 1990; Moras and Dieck, 1992). In the simplest form, JIT requires maximizing value added production activities by removing unnecessary wastes. Identification and elimination of waste and respectful treatment of employee are the two fundamental principles of a JIT system (Hobbs, 1994; Payne, 1993; Wantuck, 1983; Womack and Jones, 2003). Elimination of waste is achieved by adopting practices such as continuous quality improvement, setup time reduction, utilizing flexible resources, group technology layout, and pull production system (Gargeya, and Thompson, 1994; Sohal, Ramsay, and Samson, 1993; Suzaki, 1987)). Respectful treatment of people often means employee empowerment; it includes elements such as team work, fair compensation, employee training and new positive attitude toward suppliers (Sohal, Ramsay, and Samson, 1993; Wantuck, 1983). Unfortunately, since its beginning in mid 1980's, often a narrow view of JIT has been accepted and utilized by western manufacturers. Application of JIT to reduce inventory and increase deliveries is only a small fraction of the full potential benefits of a JIT system (Blackburn, 1991; Gilbert, 1994; Towner, 1994). To take advantage of the full benefits of JIT, one needs to have a much broader view of JIT principles (Blackburn, 1991). Looking at JIT as a process of eliminating waste and respectful treatment of employee, its principles can be applied to other areas including service areas such as healthcare, education, government, and product design and development (PDD), (Womack and Jones (2003). Application of JIT principles to PDD has great opportunity to shorten product development time, improve design quality, and reduce product development and manufacturing costs. The company that originated famous JIT system, TPS, also developed Toyota Product Development System (TPDS). TPDS employs JIT principles and tools such as value stream mapping, Kanban, 5S system, and continuous improvement to eliminate waste from product development activities and bring quality products to market faster than their leading competition (Morgan and Liker, 2006; Ward, 2007). However, TPDS is a comprehensive strategy that involves various approaches to eliminate waste from PDD activities. With regard to the question stated earlier, the objective of the article is to answer the following questions:

1. Are there similarities between JIT and CPDD practices?
2. Are there differences between PDD performances for JIT companies using CPDD and conventional companies?

The remainder of the article is organized in the following manner: First, an overview of the differences between conventional sequential method and recent CPDD is presented. Second, the article compares and analyzes similarities between JIT and CPDD for a number of critical elements followed by a set of test of hypotheses on similarities between the elements. Third, the article tests PD performances for conventional sequential method and CPDD method. Research methodology, results, and conclusion are the final sections of the article.

## SEQUESNTIAL AND COLLABORATIVE METHODS OF PDD

PDD process is a sequence of inter-connected activities in which information regarding customer needs is translated into final product design. In a traditional PDD nethod, also known as sequential or “over-the-wall” approach, the PDD process typically involves phases such as idea generation and validation, preliminary design, final design and prototyping, and pilot production and ramp-up (Wheelwright and Clark, 1992; Russell, and Taylor, 1998). Traditionally, this design process is managed sequentially by personnel from various functions of the organization. A major drawback of this approach is that the output from one design stage is passed to the next stage with little or no communication. Lack of communication and feedback among sequential stage causes the process to require too many design changes which causes the process to require longer development time which indeed causes the process to be too slow, too costly, and often of poor quality. The two elements of long delay and design changes during the delay creates a never-ending cycle where time delay causes design change and to accommodate design change it needs more time. The final result is that the designs are often rejected because the design is either outdated due to long development time or it is infeasible in term of manufacturing capability (Blackburn, 1991; Ulrich and Eppinger, 2000).

Unlike traditional “over-the-wall” approach to PDD where functional units work sequentially and downstream functions are not involved until late in the process, CPDD requires early involvement of cross functional teams. It requires that designers, manufacturers, marketers, suppliers, and customers work jointly to design product and manufacturing process in parallel. The design team must truly understand the concept of simultaneous engineering in which activities of product and process design are performed in parallel and in a coordinated manner The objective is to integrate product design and process planning into a common activity (Albers and Braun, 2011; Liang, 2009; Anderson, 2008; Clark and Fujimoto, 1991; Donnellon, 1993; Millson, Ranj, and Wilemon, 1992; Shunk, 1992). Application of CPDD under various manufacturing environments in order to shorten development time, improve quality, reduce risks, and reduce development cost is reported by these researchers (Anderson, 2008; Skalak, 2002; Kowang and Rasli, 2011; Lofstrand, 2010; Moges, 2009). Due to early cross-functional communication, CPDD approach enables an organization to be more innovative in terms of improving design quality, shortening development time, reducing design risks, and reducing development and manufacturing costs (Blackburn, 1991; Ulrich, and Eppinger, 2000; Arora and Mital, 2012; Katzy et.al, 2012; Zirger and Hartley, 1996).

## COMPARISON OF JIT MANUFACTURING AND CPDD ELEMENTS

For the past few decades, there has been an extensive volume of research in the area of JIT. As a result, there is a set of generally accepted guidelines that organizations can follow to achieve manufacturing success. However, there has been limited research on the application of JIT principles to PDD and there is no comparable set of guidelines for successful management of PDD process. Recently, a number of world class PDD companies have attempted to apply the principles of JIT manufacturing to PDD activities. The company that started the most famous JIT system, Toyota Production System (TPS) is also started Toyota Product Development System (TPDS). TPDS employs JIT principles and enable the company to bring the highest quality products to market faster than their leading competition. Also, a number research on the application of JIT principles to PDD process has shown that achieving certain manufacturing process improvement such as reducing variation, reducing rework and yield loss, solving process bottlenecks, and managing capacity, can significantly reduce PDD times.

Similarities between JIT and CPDD for a number of critical elements are shown in Table 1, (Blackburn, 1991; Spencer and Guide, 1995). Following is a brief comparison and analysis of selected factors in Table 1:

Table 1. Comparison of JIT and CPDD Elements

| Element | JIT | CPDD |
|---|---|---|
| Layout | GT/Cellular manufacturing | Project/Design teams |
| Process and information flow | Two way flow: material downward, information backward | Parallel activities: Two way flow of information among team members |
| Bottleneck | Focus is on elimination of bottleneck to shorten lead time. | Focus is on elimination of bottleneck to shorten PDD time. |
| Set-up/Transition time | Short | Short |
| Lot size | Small | Small (batches of information) |
| Quality | Quality at the source, continuous quality improvement, low rework activities | Early detection of design quality problems, continuous design improvement, low redesign activities |
| Inventory | Low | Low |
| Manufact./Develop. Cost | Reduced | Reduced |
| Lead time | Fast delivery | Short development time |
| Customer focus/Market responsiveness | More responsive to changes in customer demand | More responsive to product design changes |
| Workeforce empowerment and teamwork | High | High |
| Workforce flexibility | High | High |
| Scheduling | Localized team control, team responsibility | Localized team control, team responsibility |
| Decision making | Manufacturing team | Design team |
| Supplier involvement | High level of sharing information, quality partners | High level of involvement in product development |
| Technology | Integrated systems, new technology after process simplification | Integrated CAD, CAE, CAM |
| Workplace organization | Utilizes 5S practices to organize, clean, and sustain the workplaces | Utilizes 5S practices to organize design team and data for easy access to information to conduct PDD activities |
| Standardization | Standardization of parts and components is a critical component of JIT | Creates a standard method of doing activities (i.e. data collection, flow charting, blue prints, etc.) |
| Value added | High | High |

**Layout**

Layout in JIT environment is often in the form of product focus and manufacturing cells. This type of layout is necessary because small lot size production requires that the layout to be compact and efficient to ensure smooth flow of materials and close communication between work stations.

Unlike conventional manufacturing, where material is pushed forward, the flow in a JIT environment is in two directions; material is pulled forward, but information flows backward to provide feedback on performance and material requirements.
In CPDD, overlapping of a large number of activities requires a complete change in layout that facilitates communication and encourages team work. Instead of organizing by sequential functions, CPDD emphasizes on cross-functional integration and the formation of a design team. The design team sits together in one location, creating a type of project layout. A project layout creates an environment for frequent, two-way communication between team members, which encourages concurrent development of a product and its associated processes.

**Employee and Supplier Involvement**

In JIT environment, management encourages employee involvement and team work. The responsibility for job scheduling and quality are often passed to the teams at the shop floor. Due to small lot size production, delegation of authority to the teams at the shop floor is essential for smooth production flow. Also, in JIT suppliers work closely with manufacturing organization to improve quality and shorten delivery time.

Similar to JIT, in CPDD the responsibility for scheduling of the activities pushed down to product development team at the lowest level. Passing responsibility down to the team is essential to achieve a high level of activity coordination and information sharing among team members. Also, in CPDD suppliers work closely with the design team to reduce development costs, shorten development time, and offer ideas toward improving the quality of the design.

**Quality**

In JIT and CPDD environments, organizations are often proactive and quality means getting it right the first time. In JIT, since batch sizes are small quality at the source and continuous quality improvement are the main foundations. Shop floor workers are empowered to become their own inspectors responsible for the quality of their output. In CPDD, because of the teamwork and two-way flow of information between team members, and utilization of quality improvement tool such as six sigma process quality problems are detected earlier and solved before they have a cumulative impact on the rest of the project (Chakravorty and Franza, 2009).

**Technology**

In a JIT system, technology is not viewed as a substitute, or shortcut to process improvement. Rather, technology has been utilized after process analysis and simplification has been performed. The role of technology in CPDD is also enormous; it requires that the design team with diverse expertise makes a large number of interrelated decisions regarding the form, fit, function, cost, quality, and other aspects of the design (Karagozoglu and Brown, 1993). This requires supply and processing of relevant information from multiple sources in a coordinated manner. Successful organizations use technology in their PDD process similarly to the way they use technology in their JIT system. In CPDD, the design team utilizes appropriate technologies and tools at various stages of PDD process. Effective use of technologies and tools can dramatically shorten PDD time, reduce number of prototypes, cut costs, and improve quality of the design (McKay et al. 2011; Yamamoto and Abu Qudiri 2011; Roulet et.al (2010). The key to the success of technology in CPDD is building an effective design team with open cross-functional communication lines.

## ELEMENT HYPOTHESES

Comparison and analysis of elements in Table 1 show a high degree of similarities between JIT and CPDD elements. To study further, a set of twenty five hypotheses (H1-H25) that statistically test similarities between JIT and CPDD elements will be presented. The hypotheses are shown in Table 2. Each hypothesis in Table 2 consists of two parts- a and b. In part a, the test is conducted for JIT elements and the corresponding test for CPDD elements is conducted in part b. The last hypothesis examines the overall impact of JIT principles on CPDD.

**Hypotheses (H1-H25):**
*There is a high degree of similarities between JIT manufacturing and CPDD elements.*

## PRODUCT DESIGN AND DEVELOPMENT PERFORMANCES

The following dimensions of quality, time, competency, development cost, and manufacturing cost are used to measure the performance of PDD (Ulrich and Eppinger, 2000; Wheelwright and Clark, 1992):

### Quality

Quality is ultimately reflected in the price customers are willing to pay, the market share, and the bottom line profit. In PDD, quality problems are often the results of incomplete information and miscommunication among various functions. Quality often means a minimal number of redesign or rework. In this article, number of design changes during the development process and early manufacturing phase is used as a measure of design quality.

### Development time

Development time is the length of time between initial idea generation until new product is ready for introduction to the market. Shorter development time raises the competitive value of new product in terms of premium price, larger market share, and higher profit margin.

### Development competency

Development competency is the ability of the organization to develop future products better, faster, and cheaper. Competent workforce and effective use of technologies are important elements of organizational PDD competency. Frequency of new product introduction to the market is used as a measure of development competency.

### Development cost

This is the total cost from the early idea generation until the product is ready for manufacturing. For most organizations, development cost is usually a significant portion of the budget and must be considered in light of budget realities and the timing of budget allocations.

### Manufacturing cost

Manufacturing cost includes initial investment on equipments and tools as well as the incremental cost of manufacturing the product. There is a close relationship between manufacturing cost and the type of decisions made during the early design stage.

Table 2. Survey Items for Comparison of JIT and CPDD Elements
(1=strongly disagree, 5=strongly agree)

| | |
|---|---|
| 1a. In JIT, layout is often in form of group technology (GT) or cellular manufacturing (CM). | 1b. In CPDD, the layout emphasizes is on cross-functional integration and formation of project or design team. |
| 2a. In JIT, GT or cellular manufacturing layout allows smooth flow of materials downward and information flow backward. | 2b. In CPDD, project layout formed by the design team allows frequent and two way flow of information among team members. |
| 3a. In JIT, the focus is on identification and elimination of bottleneck to shorten manufacturing lead time. | 3b. In CPDD, the focus is on identification and elimination of bottleneck to shorten PDD time. |
| 4a. JIT system requires short set-up time. | 4b. CPDD requires fast transition (i.e. short set-up time) from one part of the design to another. |
| 5a. JIT system requires production of small lot-sizes. | 5b. In CPDD, continuous and two-way flow of information among team members is equivalent to releasing small batches of information. |
| 6a. In JIT, due to production of small lot-size, quality at the source and continuous quality improvement are essential to the success of the system. | 6b. In CPDD, due to simultaneous development of product and process, early detection of design quality problems and continuous improvement of the design are essential to the success of PDD process. |
| 7a. In JIT, production of small lot-size is associated with improving quality. | 7b. In CPDD, continuous and two-way communication among team members encourages early detection of the design problems, which is associated with improving design quality. |
| 8a. In JIT, production of small lot-size is associated with reducing inventory. | 8b. In CPDD, continuous and two-way communication among team members associated with reducing unnecessary amount of information among team members. |
| 9a. In JIT, production of small lot-size is associated with reducing manufacturing cost. | 9b. In CPDD, continuous and two-way communication among team members encourages early detection of the design problems, avoids costly design changes, which is associated with reducing development cost. |
| 10a. In JIT, production of small lot-size and smooth flow of materials downward and information flow backward is associated with reducing delivery time. | 10b. In CPDD, continuous and two-way communication among team members encourages early detection of the design problems, avoids time consuming design changes, which is associated with reducing PDD time. |
| 11a. In JIT, organizations are more responsive to the changes in customer demand. | 11b. In CPDD, the design teams are more responsive to the changes in product design. |
| 12a. In JIT, management encourages workforce empowerment and teamwork. | 12b. In CPDD, management encourages employee empowerment and teamwork. |
| 13a. JIT requires high level of workforce flexibility. | 13b. CPDD requires high level of design team flexibility. |

Table 2. Survey Items for Comparison of JIT and CPDD Elements
(1=strongly disagree, 5=strongly agree) (Continue)

| | |
|---|---|
| 14a. In JIT, detailed shop floor responsibilities such as job and employee scheduling are passed to the local teams. | 14b. In CPDD, detailed design responsibilities such as development activities and employee scheduling are passed to the design teams. |
| 15a. In JIT, suppliers work closely with manufacturing teams. | 15b. In CPDD, suppliers work closely with the design and development teams. |
| 16a. In JIT, close relationship between suppliers and manufacturing teams is essential in improving quality, reducing manufacturing cost, and shortening delivery time. | 16b. In CPDD, close relationship between suppliers and design and development teams is essential in improving design quality, reducing design and development cost, and shortening design and development time. |
| 17a. In JIT, new technologies such as robots are integrated into manufacturing system after process analysis and simplification has been performed. | 17b. In CPDD, new technologies such as IT and CAD are integrated into the design and development process after process analysis and simplification has been performed. |
| 18a. JIT utilizes 5S practices to organize, clean, and sustain the workplaces. | 18b. CPDD utilizes 5S practices to organize data and design team members for easy access to timely information to conduct PDD activities. |
| 19a. JIT utilizes tools such as flow charts and VSM to eliminate wastes throughout manufacturing and supply chain process. | 19b. CPDD utilizes tools such as QFD and VSM to eliminate wastes during design and development process. |
| 20a. JIT utilizes manufacturing fail safing to minimize defects throughout manufacturing process. | 20b. CPDD utilizes PDD fail safing approach to minimize defects design and development process |
| 21a. In JIT, standardization of parts and components is a critical component of the system. | 21b. In CPDD, standard method of doing activities such as data collection and organization is a critical component of the process. |
| 22a. In JIT, due to the principles of elimination of wastes, process activities contain high value added content | 22b. In CPDD, simultaneous communication among team members, PDD process contain high value added content. |
| 23a. As compared with traditional organizations, JIT companies are generally better in the alignment of their manufacturing strategy and tactics. | 23b. As compared with traditional PDD, CPDD teams are generally better in the alignment of their PDD strategy and tactics. |
| 24a. In JIT, performance metrics track progress toward organizational goals. | 24a. In CPDD, PDD performance metrics track progress toward organizational goals. |
| 25a. In JIT, elimination of wastes and respectful treatment of people are the two main principles. | 25b. Similar to JIT, the main principles of elimination of wastes and respectful treatment of people are applicable to CPDD. |

## PERFORMANCE HYPOTHESES

In the second set of hypotheses (H26-H30), the differences between PDD performances for JIT manufacturing companies and conventional companies are tested.

**<u>Hypotheses (H26-H30):</u>**

*H26: By utilizing CPDD approach, JIT companies are able to design new products with fewer design changes than conventional companies(better quality).*

*H27: By utilizing CPDD approach, JIT companies are able to design new products faster than conventional companies.*

*H28: By utilizing CPDD approach, JIT companies are able to design new products more often than conventional companies.*

*H29: By utilizing CPDD approach, JIT companies are able to design new products with less development cost than conventional companies.*

*H30: By utilizing CPDD approach, JIT companies are able to design new products with less manufacturing cost than conventional companies.*

## RESEARCH METHODOLOGY

The target population for this study consisted of manufacturing firms in the states of Illinois, Indiana, Ohio, Michigan, and Wisconsin. A sample of manufacturing firms with more than 50 employees was chosen from manufacturers' directories of those states. The sample covers organizations in variety of industries ranging from fabricated metal, communication, electronics, automotive, toots, chemicals, rubber, and paper products. A comprehensive survey instrument based on examination of the literature and critical elements listed in Table 1 was developed. A panel of practitioners and researchers with experience in JIT and PDD was used to validate the survey. In addition to general organization and managerial profile items, the survey contained 50 items (25 paired) regarding similarities between JIT and CPDD elements. The twenty five paired questionnaire items are shown in Table 2.

Also, the survey instrument contained a number of questionnaire items on PDD performances for JIT companies using CPDD and conventional companies. Out of 91 completed surveys received, 84 surveys were usable resulting in a response rate of 17%. Based on a number of questionnaire items on the principles of JIT practices, 33 organizations were grouped as JIT companies and 51 organizations were categorized as conventional companies.
The survey data indicates that majority of respondents had various high level managerial positions from organization with less than 500 employees. Presidents and vice presidents accounted for 29% and plant managers accounted for 30% of the sample. About 35% of the sample had other managerial positions such as operations/production managers, quality managers, and the remaining 6% were production line supervisors. In terms of manufacturing and PDD experience, about 28% of the respondents had between 10 to 20 years and 60% had more than 20 years of manufacturing experience. About 72% of the sample had more than 10 years of JIT experience and close to 65% of the sample had more than 10 years of PDD experience.

## RESEARCH RESULTS

As stated earlier, in the first set of hypotheses the objective was to examine similarities between JIT and CPDD for a set of paired elements shown in Table 2. For each item, the null hypothesis was that the mean response for JIT is equal to the mean response for CPDD. The differences

Table 3. Comparison of JIT and CPDD Elements (1=strongly disagree, 5=strongly agree)

| | JIT | | CPDD | | | |
|---|---|---|---|---|---|---|
| **Element** | **Mean** | **SD*** | **Mean** | **SD*** | **P-Value** | **Correlation** |
| 1. Layout | 3.92 | 0.85 | 3.62 | 1.08 | 0.140 | 0.74 |
| 2. Flow | 4.08 | 1.03 | 4.06 | 0.96 | 0.640 | 0.83 |
| 3. Bottleneck | 4.27 | 1.33 | 4.15 | 1.12 | 0.540 | 0.71 |
| 4. Set-up | 4.34 | 0.70 | 3.81 | 0.96 | 0.003 | 0.47 |
| 5. Lot-size | 3.85 | 0.88 | 3.55 | 1.03 | 0.100 | 0.65 |
| 6. Quality at source | 4.23 | 0.77 | 4.28 | 0.74 | 0.300 | 0.69 |
| 7. Quality Improv. | 3.43 | 0.90 | 3.89 | 0.85 | 0.000 | 0.32 |
| 8. Inventory | 4.22 | 0.80 | 3.96 | 0.85 | 0.150 | 0.62 |
| 9. Manufacturing cost | 3.58 | 0.80 | 3.94 | 0.67 | 0.001 | 0.45 |
| 10. Delivery | 4.26 | 0.75 | 4.31 | 0.72 | 0.280 | 0.75 |
| 11. Customer respons. | 4.22 | 0.73 | 4.24 | 0.70 | 0.480 | 0.79 |
| 12. Teamwork | 3.98 | 0.81 | 3.83 | 0.90 | 0.360 | 0.76 |
| 13. Flexibility | 3.86 | 0.93 | 3.72 | 0.96 | 0.330 | 0.65 |
| 14. Team scheduling | 3.72 | 0.78 | 3.76 | 0.78 | 0.240 | 0.82 |
| 15. Suppliers | 3.77 | 0.79 | 3.82 | 0.83 | 0.350 | 0.77 |
| 16. Suppliers & teams | 4.23 | 0.72 | 4.02 | 0.70 | 0.390 | 0.73 |
| 17. Technology | 3.53 | 0.96 | 3.68 | 0.94 | 0.072 | 0.69 |
| 18. 5S Practices | 4.30 | 0.92 | 4.12 | 0.84 | 0.310 | 0.71 |
| 19. Flowcharts/VSM | 4.11 | 1.12 | 3.88 | 1.18 | 0.281 | 0.75 |
| 20. Fail-safing | 4.23 | 1.31 | 4.06 | 1.42 | 0.352 | 0.81 |
| 21. Standardization | 4.22 | 0.87 | 3.84 | 0.88 | 0.320 | 0.67 |
| 22. Value added | 4.28 | 1.12 | 4.13 | 0.98 | 0.160 | 0.72 |
| 23. Alignment | 4.36 | 1.25 | 4.17 | 1.17 | 0.210 | 0.76 |
| 24. Performn Meas. | 4.24 | 1.22 | 4.05 | 1.16 | 0.181 | 0.77 |
| 25. Overall | 4.56 | 0.93 | 4.29 | 0.96 | 0.140 | 0.73 |

* SD = Standard deviation

between the mean responses for JIT and CPDD were compared using the statistical t-test. The respondents were asked to rate each element of Table 2 based on the degree of their agreement (1=strongly disagree, 5=strongly agree) to the question. Table 3 shows the result of similarities between JIT and CPDD.

As shown in Table 3, overall the respondents strongly agreed with the statements regarding similarities between JIT and CPDD elements. The mean ratings for about 70% of the elements for both JIT and CPDD are above 3.80. Specifically, out of twenty hypotheses, the respondents agreed that there is a high degree of similarities between JIT and CPDD for all except three hypotheses H4, H7, and H9.

For H4, the mean ratings for JIT and CPDD are respectively 4.34 and 3.81. This means although the respondents understood that short set-up and fast transition time are the main requirements of successful JIT and CPDD, the relationship between short set-up and JIT was much stronger. This is a reasonable result because an average manufacturing manager has longer experience with JIT than CPDD. They clearly understood that successful JIT requires small lot-size and small lot-size requires short set-up time. However, due to their shorter experience with CPDD and because CPDD is primarily an information processing process, the links between small batches of information and fast transition time is not clear. H7 hypothesizes the relationships between small lot-sizes and quality improvement for both JIT and CPDD. For this test, the mean ratings for JIT and CPDD are respectively 3.43 and 3.89. This indicates for an average manager it is easier to recognize the relationship between CPDD and quality improvement than the relationship between JIT and quality improvement. The higher rating for CPDD is perhaps due to continuous and two way communication among design team members, which encourages early detection of the design problem. The JIT result is also consistent with the literature because although total quality management and quality improvement are fundamental requirements of successful JIT, an average manufacturing manager has difficulty to understand this relationship. The relationships between small lot-size and reduced manufacturing cost in JIT and the relationship between small batches of information and reduced development cost in CPDD are examined in H9. The mean ratings for JIT and CPDD are respectively 3.58 and 3.94. For the same reasons as H7, this means for an average manager it is easier to understand this relationship in CPDD than JIT. The JIT result is interesting and also consistent with the literature because reduced manufacturing cost in JIT is primarily due to elimination of wastes, a fundamental principle of JIT, and an average manufacturing manager has difficulty to see this relationship. The overall impact of JIT principles on JIT and CPDD is examined in H24. It is obvious that the data supports the hypothesis as the mean ratings for JIT and CPDD are respectively 4.56 and 4.29 indicating strong agreement with the statements that the main principles of waste elimination and respectful treatment of people in JIT can also be applied in CPDD.

The last column of Table 3 shows correlation coefficients between JIT and corresponding CPDD elements. The correlation coefficients in Table 3 strongly support the above analysis. With the exception of three hypotheses H4, H7, and H9 other coefficients are greater than 0.60 indicating a high degree of linear association between JIT and CPDD elements.

The performance hypotheses (H26-H30) state that by utilizing CPDD approach, JIT companies are able to design new products with fewer design changes, faster, more often, with less development cost, and less manufacturing cost than conventional companies.

Table 4. PDD Performances for Conventional and JIT Companies using CPDD

| **Factor** | **Mean Conventional** | **Mean JIT** | **p-value** |
|---|---|---|---|
| Number of design changes | 5.36 | 3.28 | 0.004 |
| Development time (Months) | 37.22 | 24.73 | 0.003 |
| Development competency (Months) | 49.46 | 32.72 | 0.005 |
| Development cost | 144.60* | 100* | 0.005 |
| Manufacturing cost | 135.75* | 100* | 0.005 |

* data reported in terms of percent improvement

Table 4 provides useful statistical information regarding PDD performances for JIT and conventional companies. The average number of design changes for conventional and JIT companies are respectively 5.36 and 3.28, a quality improvement of 63%. The average development time for conventional and JIT companies are respectively 37.52 and 24.73 months, an improvement of 52%. For development competency, the average time between introduction of new products for conventional companies is 49.46 months and 32.72 months for JIT companies, an improvement of 51%. Table IV also indicates that JIT organizations enjoy a 45% reduction in PDD cost and 36% reduction in manufacturing cost. From the last column of

Table 4, it is clear that the hypotheses are strongly supported by the data as the p-value for all five hypotheses is less than 0.005.

## CONCLUSION

The focus of this article was to demonstrate possible links between JIT practices and CPDD. First, comparison and analysis of a number of elements showed remarkable similarities between JIT practices and CPDD. Second, a set of paired hypotheses was used to test similarities between JIT practices and CPDD elements. Statistical results clearly support the hypotheses regarding similarities between JIT and CPDD for majority of elements. Specifically, out of twenty four hypotheses, the respondents agreed that there is a high degree of similarities between JIT and CPDD for all but three hypotheses. The last pair of hypotheses that examines the overall impact of JIT principles is especially important. Statistical results strongly agreed that the main principles of waste elimination and respectful treatment of people in JIT is also applicable to CPDD. The correlation coefficients between JIT and CPDD elements also supported the same result. Third, statistical results also indicate that compared with conventional companies, JIT companies are able to develop new products with 63% better quality, 52% less development time, 45% less development cost, and 36% less manufacturing cost. Also frequency of new product introduction is 51% faster than conventional companies.

In summary, statistical results of this article clearly show strong links between JIT practices and CPDD. Managerial implication of the research is that successful implementation of JIT principles goes much beyond inventory reduction and frequent deliveries. For JIT organizations success in CPDD is the result of knowledge and technology transfer from their JIT system into their PDD process.

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