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Using Principles of Lean Manufacturing to Enhance New Product Development

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Abstract

The objective of this article is to demonstrate the relationship between lean manufacturing (LM)practices and integrated method of new product development (INPD). Comparison and analysis of several critical factors show high degree of resemblances between the two set of factors. A number of hypotheses regarding similarities between LM and INPD factors were developed and tested. Survey data from a sample of 500 manufacturing organizations strongly supports the hypotheses regarding similarities between LM and INPD factors. Statistical results also indicate by utilizing INPD, lean manufacturing organizations are able to develop new products with 63% better quality, 52% less development time, 45% less development cost, and 36% less manufacturing cost.

***Key words**: New Product Development, Lean Manufacturing, Integrated NPD*

1. INTRODUCTION

In today's 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, and introduction quickly has been the hallmark of successful world class organizations (Jacobs and Chase, 2014; Ferioli et al. 2010; Roulet et al. 2010; Beauregard et al. 2014; Kerga et al. 2014). Early introduction of new products to the market has several strategic and tactical advantages. It often means charging 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 (Cooper and Kleinschmidt, 1994; Lofstrand, 2010; Zahra and Ellor, 1993).

Despite its well-known critical role, for large number of manufacturing organizations successful management of new product development (NPD) has often been a major challenge. Long development time, prohibitive development and manufacturing costs, and questionable quality has been the common result for many of these organizations. Perhaps the primary contributing factor to such unsuccessful result is the use conventional sequential method of NPD by these organizations (Blackburn, 1991; Morgan and Liker, 2006; Arora and Mital (2012).In contrast, manufacturing literature for the past three decades clearly shows that through their lean manufacturing practices, 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; Tang et.al, 2015; Ulrich and Eppinger, 2004; Michael, 2008; Unger and Eppinger 2009).Instead of traditional sequential approach to NPD, a successful strategy employed by these world class organizations is integrated method of new product development (INPD). The question of interest in this article is: Are there relationships between success in lean manufacturing (LM) practices and success in INPD?

2. LITERATURE REVIEW

Lean manufacturing has been a great force in the world of manufacturing since mid 1980's. Some of the main benefits of a LMsuch 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, LM 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 LM 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 positive attitude toward suppliers (Sohal, Ramsay, and Samson, 1993; Wantuck, 1983).Looking at LM 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 NPD (Womack and Jones, 2003; Saunders et al. 2014; Gilbert, 1994).Application of lean principles to NPD has great opportunity to shorten product development time, improve design quality, and reduce product development and manufacturing costs (Anand and Kodali, 2008). The company that originated famous LM system known as Toyota production System (TPS), also has developed Toyota Product Development System (TPDS). TPDS employs LM principles and tools such as value stream mapping, Kanban, 5S system, and continuous improvement to eliminate waste from product development activities and bring quality designed products to market faster than their leading competition (Morgan and Liker, 2006; Ward, 2007). TPDS is a comprehensive strategy that involves various approaches to eliminate waste from NPD activities. The focus of this article is on special case of TPDS called integrated method of new product development (INPD).With regard to the question stated earlier, the objective of the article is to answer the following questions:

1. Are there similarities between LM and INPD practices?
2. Are there differences between NPD performances for LM companies using INPD and conventional companies using sequential method of NPD?

Sequesntial and Integrated Methods of NPD

NPD process is a sequence of inter-connected activities in which information regarding customer needs is translated into final product design. In a sequesntial NPD method, the process typically involves phases such as idea generation and validation, preliminary design, final design, prototyping, and pilot production and ramp-up (Wheelwright and Clark, 1992; Russell, and Taylor, 1998). Traditionally, the 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 processto require longer development time which indeed causes the process to be too slow, too costly, and often of poor quality. The final result is that the design is 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 method where functional units work sequentially and downstream functions are not involved until late in the process, INPD requires early involvement of cross functional teams. It requires that designers, manufacturers, marketers, suppliers, and customers work jointly as a team in an integrated manner (Albers and Braun, 2011; Liang, 2009; Anderson, 2008; Clark and Fujimoto, 1991;Donnellon, 1993; Millson, Ranj, and Wilemon, 1992; Montagna, 2015; Shunk, 1992).Application of INPD 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, INP Dapproach 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; Harland and Zakir, 2014; Arora and Mital, 2012; Katzy et.al, 2012; Zirger and Hartley, 1996).

Comparison of Lean Manufacturing and INPD Factors

For the past few decades, there has been an extensive volume of research in the area of LM. 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 LM principles to NPD and there is no comparable set of guidelines for successful management of NPD process. Recently, a number of world class NPD companies have attempted to apply the principles of lean manufacturing to NPD activities. The company that started the most famous LM system, Toyota Production System (TPS) is also started Toyota Product Development System (TPDS). TPDS employs lean principles and enable the company to bring the highest quality products to market faster than their leading competition. Similarities between LM and INPD for a number of critical factors are shown in Table 1, (Blackburn, 1991; Spencer and Guide, 1995).

Table 1. Comparisonof LM and INPD Factors

Factor	LM	INPD
Layout	GT/Cellular manufacturing	Project/Design teams
Process and information flow	Two wayflow: material downward, information backward	Parallel activities: Two way flow of information among team members
Set-up/Transition time	Short	Short
Lot size	Small (Kanban system)	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 empowermentand 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 NPD activities
Standardization	Standardization of parts and components is a critical component of LM	Creates a standard method of doing activities (i.e. data collection, flow charting, blue prints, etc.)
Value added	High	High

Following is a brief comparison and analysis of selected factors in Table 1:

Layout

Layout in LM 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 LM environment is in two directions; material is pulled forward, but information flows backward to provide feedback on performance and material requirements.

In INPD, 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, INPD 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.

Lot Size

In contrast to conventional manufacturing, lean manufacturing requires production of small lot-sizes. Production of small lot-sizes is possible by drastically reducing set-up times. It is well documented that production of small lot-sizes in LM is closely associated with improved quality, reduced inventory, faster delivery, and more responsive to market demands.

Similar to LM, INPD also utilizes small lot-sizes; the only difference is that in LM small lot sizes of goods are processed but INPD requires small lot-sizes of information. That is, continuous two way communication in INPD is similar to early release of small batches of information (Blackburn, 1991; White, 1993). With the early release of small batches of information, downstream constituents can begin working on different phases of the design while final design is evolving. The early release of information reduces uncertainty and encourages early detection of problems, which enables organizations to avoid costly, time-consuming changes.

Employee and Supplier Involvement

In LM 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 LM suppliers work closely with manufacturing organization to improve quality and shorten delivery time.

Similar to LM, in INPD 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 INPD 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 LM and INPD environments, organizations are often proactive and quality means getting it right the first time. In LM, 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 INPD, 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 LM 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 INPD 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 NPD process similarly to the way they use technology in their LM system. In INPD, the design team utilizes appropriate technologies and tools at various stages of NPD process. Effective use of technologies and tools can dramatically shorten NPD 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 INPD is building an effective design team with open cross-functional communication lines.

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3. FACTOR HYPOTHESES

Comparison and analysis of factors in Table1show a high degree of similarities between LM and INPD. To study further, a set of twenty hypotheses (H1-H20) that statistically test similarities between LM and INPD will be presented. The questionnaire items for the hypotheses are shown in Table 2. Each questionnaire item in Table 2 consists of two parts. In part a, the item makes a statement regarding LM factor and the corresponding statement regarding INPD factor is made in part b. The last hypothesis examines the overall impact of LM principles on INPD.

Table 2.Survey Items for Comparison of LM and INPD Factors
(1=strongly disagree, 5=strongly agree)

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

13a. In LM, detailed shop floor responsibilities such as job and employee scheduling are passed to the local teams.	13b. In INPD, detailed design responsibilities such as development activities and employee scheduling are passed to the design teams.
14a. In LM, suppliers work closely with manufacturing teams.	14b. In INPD, suppliers work closely with the design and development teams.
15a. In LM, close relationship between suppliers and manufacturing teams is essential in improving quality, reducing manufacturing cost, and shortening delivery time.	15b. In INPD, 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.
16a. In LM, new technologies such as robots are integrated into manufacturing system after process analysis and simplification has been performed.	16b. In INPD, new technologies such as IT and CAD are integrated into the design and development process after process analysis and simplification has been performed.
17a. LM utilizes 5S practices to organize, clean, and sustain the workplaces.	17b. INPD utilizes 5S practices to organize data and design team members for easy access to timely information to conduct NPD activities.
18a. In LM, standardization of parts and components is a critical component of the system.	18b. In INPD, standard method of doing activities such as data collection and organization is a critical component of the process.
19a. In LM, due to the principles of elimination of wastes, process activities contain high value added content	19b. In INPD, simultaneous communication among team members, NPD process contain high value added content.
20a. In LM, elimination of wastes and respectful treatment of people are the two main principles.	20b. Similar to LM, the main principles of elimination of wastes and respectful treatment of people are applicable to INPD.

Hypotheses (H1-H20):
There is a high degree of similarities between LM and INPD factors.
New Product Development Performances

The following dimensions of quality, time, competency, development cost, and manufacturing cost are used to measure the performance of NPD (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 NPD, 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 NPD 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. Although early design decisions determine about 70 percent of future manufacturing cost, organizations often spend far too little time

and resources during this stage (Huthwaite, B. 1991). To save future manufacturing cost, it is prudent for the companies to spend more time and resources during the early design phases of NPD process where critical design decisions are made.

Performance Hypotheses

In the second set of hypotheses (H21-H25), the differences between NPD performances for lean manufacturing companies and conventional companies are tested.

Hypotheses (H21-H25):

H21:By utilizing INPD approach, LM companies are able to design new products with fewer design changes than conventional companies(better quality).

H22: By utilizing INPD approach, LM companies are able to design new products faster than conventional companies.

H23: By utilizing INPD approach, LM companies are able to design new products more often than conventional companies.

H24: By utilizing INPD approach, LM companies are able to design new products with less development cost than conventional companies.

H25: By utilizing INPD approach, LM companies are able to design new products with less manufacturing cost than conventional companies.

4. 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 500 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 factors listed in Table 1 was developed. A panel of practitioners and researchers with experience in LM and NPD was used to validate the survey. In addition to general organization and managerial profile items, the survey contained 40 items (20 paired) regarding similarities between LM and INPD factors.

Also, the survey instrument contained a number of questionnaire items on NPD performances for LM companies using INPD 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 LM practices, 33 organizations were grouped as LM 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 NPD 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 LM experience and close to 65% of the sample had more than 10 years of NPD experience.

Research Results

As stated earlier, in the first set of hypotheses the objective was to examine similarities between LM and INPD for a set of paired factors shown in Table 2. For each item, the null hypothesis was that the mean response for LM is equal to the mean response for INPD. The differences between the mean responses for LM and INPD were compared using the statistical t-test. The respondents were asked to rate each element of Table2 based on the degree of their agreement (1=strongly disagree, 5=strongly agree) to the question. Table 3 shows the statistical results of the similarities between LM and INPD factors.

Table 3.Statistical Result of Comparison of LM and INPD Factors
(1=strongly disagree, 5=strongly agree)

	LM		**INPD**			
Factor	**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. Set-up	4.34	0.70	3.81	0.96	0.003	0.47
4. Lot-size	3.85	0.88	3.55	1.03	0.100	0.65
5. Quality at source	4.23	0.77	4.28	0.74	0.300	0.69
6. Quality Improv.	3.43	0.90	3.89	0.85	0.000	0.32
7. Inventory	4.22	0.80	3.96	0.85	0.150	0.62
8. Manufacturing cost	3.58	0.80	3.94	0.67	0.001	0.45
9. Delivery	4.26	0.75	4.31	0.72	0.280	0.75
10. Demand	4.22	0.73	4.24	0.70	0.480	0.79
11. Teamwork	3.98	0.81	3.83	0.90	0.360	0.76
12. Flexibility	3.86	0.93	3.72	0.96	0.330	0.65
13. Team scheduling	3.72	0.78	3.76	0.78	0.240	0.82
14. Suppliers	3.77	0.79	3.82	0.83	0.350	0.77
15. Suppliers & teams	4.23	0.72	4.02	0.70	0.390	0.73
16. Technology	3.53	0.96	3.68	0.94	0.072	0.69
17. 5S Practices	4.30	0.92	4.12	0.84	0.310	0.71
18. Standardization	4.22	0.87	3.84	0.88	0.320	0.67
19. Value added	4.28	1.12	4.13	0.98	0.160	0.72
20. Overall	4.56	0.93	4.29	0.96	0.140	0.73

* SD = Standard deviation

As shown in this table, overall the respondents strongly agreed with the statements regarding similarities between LM and INPD factors. The mean ratings for about 70% of the factors for both LM and INPD are above 3.80. Specifically, out of twenty hypotheses, the respondents agreed that there is a high degree of similarities between LM and INPD for all except three hypotheses H3, H6, and H8.

For H3, the mean ratings for LM and INPD 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 LM and INPD, the relationship between short set-up and LM was much stronger. This is a reasonable result because an average manufacturing manager has longer experience with LM than INPD. They clearly understood that successful LM requires small lot-size and small lot-size requires short set-up time. However, due to their shorter experience with INPD and because INPD is primarily an information processing process, the links between small batches of information and fast transition time is not clear. H6 hypothesizes the relationships between small lot-sizes and quality improvement for both LM and INPD. For this test, the mean ratings for LM and INPD are respectively 3.43 and 3.89. This indicates for an average manager it is easier to recognize the relationship between INPD and quality improvement than the relationship between LM and quality improvement. The higher rating for INPD is perhaps due to continuous and two way communication among design team members, which encourages early detection of the design problem. The LM result is also consistent with the literature because although total quality management and quality improvement are fundamental requirements of successful LM, an average manufacturing manager has difficulty to understand this relationship. The relationships between small lot-size and reduced manufacturing cost in LM and the relationship between small batches of information and reduced development cost in INPD are examined in H8. The mean ratings for LM and INPD are respectively 3.58 and 3.94. For the same reasons as H6, this means for an average manager it is easier to understand this relationship in INPD than LM. The LM result is interesting and also consistent with the literature because reduced manufacturing cost in LM is primarily due to elimination of wastes, a fundamental principle of LM, and an average manufacturing manager has difficulty to see this relationship. The overall impact of lean principles on LM and INPD is examined in H20. It is obvious that the data supports the hypothesis as the mean ratings for LM and INPD are respectively 4.56 and 4.29indicating strong agreement with the statements that the main principles of waste elimination and respectful treatment of people in LM can also be applied in INPD.

The last column of Table 3 shows correlation coefficients between LM and corresponding INPD factors. The correlation coefficients in Table 3strongly support the above analysis. With the exception of three hypotheses H3, H6, and H8 other coefficients are greater than 0.60 indicating a high degree of linear association between LM and INPD factors.

The performance hypotheses (H21-H25) state that by utilizing INPD approach, LM 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. NPD Performances for Conventional and LM Companies using INPD

Factor	**Mean Conventional**	**Mean LM**	**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 NPD performances for LM companies using INPD conventional companies using sequential method of NPD. The average number of design changes for conventional and LM companies are respectively 5.36and 3.28, a quality improvement of 63%. The average development time for conventional and LM companies are respectively 37.22 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 LM companies, an improvement of 51%. Table 4 also indicates that LM organizations enjoy a 45% reduction in NPD 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.

5. CONCLUSION

The focus of this article was to demonstrate possible links between LM practices and INPD. First, comparison and analysis of a number of factors showed remarkable similarities between LM practices and INPD. Second, a set of paired hypotheses was used to test similarities between LM practices and INPD factors. Statistical results clearly support the hypotheses regarding similarities between LM and INPD for majority of factors. Specifically, out of twenty hypotheses, the respondents agreed that there is a high degree of similarities between LM and INPD for all but three hypotheses. The last pair of hypotheses that examines the overall impact of LM principles is especially important. Statistical results strongly agreed that the main principles of waste elimination and respectful treatment of people in LM is also applicable to INPD. The correlation coefficients between LM and INPD factors also supported the same result. Third, statistical results also indicate that compared with conventional companies, LM 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.

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