MMRC

DISCUSSION PAPER SERIES

No. 280

Low-cost disruptive innovation by an Indian automobile manufacturer

Chaisung Lim

Miller School of MOT, Konkuk University

Seokhee Han

Dassault Systemes Korea

Hiroshi Ito

MMRC, The University of Tokyo

October 2009

東京大学ものづくり経営研究センター

Manufacturing Management Research Center (MMRC)

http://merc.e.u-tokyo.ac.jp/mmrc/dp/index.html

Low-cost disruptive innovation by an Indian automobile manufacturer

Chaisung Lim*
Miller School of MOT, Konkuk University 1 Hwayang-dong, Gwangjin-gu, Seoul 143–701, Korea
E-mail: edisonfoot@gmail.com
Fax: 82-2-450-4141
*Corresponding author

Seokhee Han
Dassault Systemes Korea, 15 floor, Mapo Tower Building, 418, Mapo dong, Mapo Ku, Seoul, 121–050, Korea
E-mail: Seokhee.HAN@3ds.com

Hiroshi Ito
MMRC, The University of Tokyo, 3-3-34 Hongo, Bunkyo-ku, Tokyo, 113-0033, Japan
E-mail: h-ito@iris.ocn.ne.jp

Abstract: This is an exploratory study examining the application of the lean principle applied product development (PD), for the BOP market, aiming at new market disruption in a developing country using a case study approach. The selected case is Nano of Tata Motor Limited(TML), the cheapest car in the world. The bottom of the pyramid (BOP) market (i.e., low income market) calls for a bottom up approach in delivering new products and services, respecting the value and affordability condition of the BOP customers. This study explores the LAPD(lean principle applied product development) process of a developing country firm in the BOP business model aiming at new market disruption. The LAPD process is a reverse exploratory process of reaching product concept, starting from a base product model, and the subsequent process of design iteration for a drastic cost reduction while maintaining essential performance appreciated by customers. The LAPD process is implemented with utilization of external sources of knowledge and utilization of the digital technology that support the PD process in order to complement the weakness of technological capability. This paper will also discuss key implications of study findings.

Keywords: Digital Technology Supporting Product Development, Lean Design, Lean Product Development, Disruptive Innovation, Low-Cost Innovation, Catching-Up Strategy, Product Development, Automobile, Bottom of the Pyramid

1. Introduction

The prior literature on the East Asian Newly Industrialized Economies (NIEs) after the World War II has revealed that the NIEs could catch up with advanced countries through their investment in the assimilation and adaptation of the technologies developed by advanced countries (Shin, 1996; OECD, 1992; Dahlman, Westphal, & Kim, 1985; Lee et al., 1988; Bell & Pavitt, 1992; Kim 1980&1997; Collins and Bosworth 1996; Wong et al. 2003) and by creating knowledge for taking advantage of new business and technological opportunities abroad (Amsden, 1989; Amsden & Chu, 2003; Kim, 1997, 2002; Ernst, 2002; Mathews, 2005; Lee & Lim, 2001; Lall, 1992, 1998; Hung 2002; Mu & Lee 2005; Ernst & O'Conner, 1989; Hobday, 1995; Lee & Lim, 2001; Lee, Lim & Song; Albert 1998; Amsden and Chu 2003; Breznitz 2005; Hung 2002; Mattews 2005). This catch up process has been achieved through the NIEs' participation in the global division of labor through OEM-ODM (Original Equipment Manufacturer-Original Design Manufacturer) production and export (Hobday, 1995; Ernst, 2002). The source of the competitiveness of firms in the NIEs lies in producing products cheaper than those in advanced countries. The main mode of PD has been imitative PD through coping, modifying available product designs, and commercializing quickly the emerging technologies from abroad. Lacking technological capability, firms from the NIEs rely on foreign suppliers for core components or materials of advanced technology and for the architecture or the technological platform of a product. As the technological capability of advanced firms in the NIEs approach that of advanced countries, the firms make a challenge to develop the components or materials which have been supplied by the foreign suppliers (Kim 1980; Lee et al 1988; Kim 1997; Hung 2002; Mattews 2005; Wong et al. 2005; Hobday 1995).

China and India have made remarkable achievements in industrial growth over the last 10 years. The most salient feature of the two economies is the size of the economy. The huge economies with fast economic growth have created immense market opportunities which are far greater than those of Korea and Taiwan who experienced similar fast economic growth. Even the lower end markets in China and India can create business opportunities. This paper examines a low cost disruptive innovation by an Indian manufacturer. The low cost innovation here refers to the innovation of making a product deliverable to low income customers at cheap cost who could not previously afford to buy. This innovation creates a new market causing disruptions in the existing competitive map.

Prahalad's (2005) book (*The Fortune at the Bottom of the Pyramid*) emphasized the important business opportunities at the lower end (*The Bottom of the Pyramid,* from here BOP) of the market in low income countries such as China, India, and Brazil. Prahalad (2004, p.4) showed that the number of people with a purchasing parity power of $1500 (USD) per year had reached 4 billion. Prahalad argued that firms need a different approach from the existing dominant approach in order to capture BOP market opportunities. Prahalad further argued that the existing approach of modifying existing products, services, and management styles are likely to fail (top down approach), while developing products and services specifically targeted at the BOP customers are desirable (bottom up approach) (Prahald 2005, p.48). The bottom up approach calls for new-to-the-world products, different from any product currently available in the global market. Multinational firms with rich experience in developing original products may be able to readily adopt this approach, whereas firms from developing countries may not have the experience necessary to bring such products to the market.

If the PD for BOP customers is defined as developing new-to-the-world product through the bottom up approach, then thereby creating a new market, then the PD is the process making a contribution to new market disruption. Christensen and Raynor referred to new market disruption where a firm disrupts the competitive environment by offering an innovative, simple-to-use product to potential customers at prices so affordable that a whole new population of people begin buying and using the product (Christensen and Raynor 2003, p. 45).

Kim and Mauborgne (1999) argued that in creating a new business model with a new idea, setting price first is important to capture the mass market. In capturing the mass market, it is argued that, instead of targeting novelty-seeking, price-insensitive customers at the launch and subsequently decreasing prices overtime to attract mainstream buyers, setting a strategic price point from the beginning to attract a large pool of customers is important (Kim and Mauborgne, 2000). When a company plans to create a new business model by developing a product for a candidate BOP market, this setting a strategic price point to attract a pool of customers large enough to guarantee profits in spite of the low price is a challenging task.

In order to offer a “cheap” price product for the BOP market, a company should be able to produce a product at ”cheap” cost. This requires a PD approach in which a drastic reduction in total cost can be achieved. The lean principle applied PD (LAPD), which aims to reduce total cost, could offer much value to the advancement of the PD for the BOP market. To examine LAPD approach more closely, the lean principle itself must be first discussed. The lean principle, which was coined by Womack and Jones (1996), includes defining value from the perspective of customers and eliminating waste and non-value adding activities. The concept of ”lean” has been applied to eliminate factory wastage in the factory. The application of the lean principle has been recently extended to the PD area. The lean design approach spread in the 2000s (Anderson, 2006). However, because PD activities are different from those activities in manufacturing, it is difficult to define non-value adding activities. The PD process is defined as the creative and iterative process of finding solutions, while the manufacturing process is a repetitive process implementing planned working processes(Nightingale 2000, Thomke and Fujimoto 2000). In the PD process, a product developer frequently gets a result (“problem” or ”error,” according to Thomke and Fujimoto (2000)) different from the expected result, allowing the developer obtain new information that may be useful for further problem solving process in PD. Seemingly non-value adding activities such as “problem” or “error” are an inevitable part of any PD process.

Baines et al. (2006) reviewed literature on the application of the lean principle in PD (key papers between 1999 and 2005). They summarized their review by proposing that the concept of lean has been applied beneficially in PD. However, the concept of lean needs to be applied carefully. Baines at al found that the definition of lean is drifting. They also proposed that its value in the PD process needs to be precisely defined, as it is not necessarily the same as its value in production operations. All of this shows that the LAPD in advanced countries are still in an inception stage. Mascitelli (2007, p.7) argued that the LAPD should address the dimension of (i) yielding products that respond to a market need, (ii) reducing integrated cost applying Toyota’s 3 P processes, design for six sigma, design for manufacturing and assembly, and value engineering, and (iii) time to market. The application of the interrelated techniques as elements of a coherent whole was emphasized in Karlsson and Ahlstrom (Karlsson & Ahlstrom, 1996).

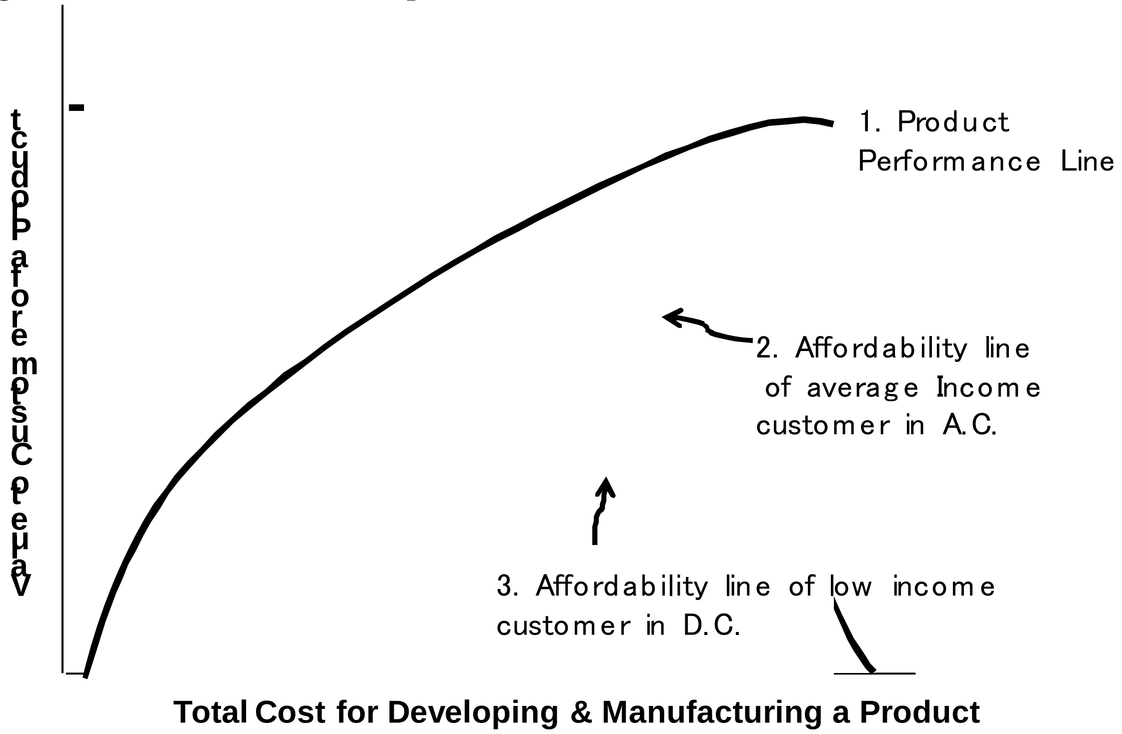
From prior literature, it could be proposed that the LAPD (i) is the PD where value is defined from the perspective of the customer and an emphasis is placed on the elimination of waste and non-value adding activities and (ii) aims at a total integrated cost through the application of available techniques at the PD stage. Because the PD for the BOP market calls for a drastic reduction in total cost of the product, the LAPD approach, which aims at a total integrated cost, could be a useful approach. In order to reduce total cost, the elimination of non-value adding activities is essential. The LAPD approach shares commonality with the fourth principle of the twelve principle of innovation for the BOP: “all innovations must focus on conserving resources: eliminate, reduce and recycle" (Prahalad 2006, p. 26). The first principle ("… Serving the BOP market is not just about lower prices. It is about creating a new price-performance envelope") shares commonality with the LAPD where customer value is respected. "Price-performance envelope" reflect the value appreciated by customers.

Even though there might be possibilities that the LAPD could be applied to PD for the BOP market, it is still unclear as to whether firms from developing countries could achieve such an endeavor. The LAPD is still in its inception stage, even in advanced countries. The LAPD process is an advanced process of PD which firms from advanced countries with full-fledged PD capabilities pursue. Firms in developing countries are less likely to have the necessary PD capabilities for developing original products for the BOP market.

This study explores the LAPD process which would be common to the developing country firm who is weak in technological capability and who have to develop new-to-the world product for the BOM market for the creation of a new market.

The LDPD process for the BOP market is targeted at developing a product with a lower performance in that in other market. In a diagram (Figure 1) modifying Browning's (Browning 2002, p.55), customer value is equated only with technical performance (as design engineers sometimes do). Then value is a function of performance and affordability (Lines 1 and 2). As money is invested in the PD, performance increases over curve 1. On the other hand, affordability decreases over line 2 as money is invested in the PD processes. Line 2 denotes the affordability of average income customers in advanced countries. Line 3 denotes the affordability of the BOP customers in developing countries. Affordability starts to decrease in the lower level of PD investment than line 2.

Figure 1 Value to customer of a product and the Total Cost of a Product



Source: Browning et al (2002, p.55 modified)

Therefore, this implies that product performance required by the BOP customers is lower than that by the average income customers in advanced countries. This further suggests that a company does not have to invest as much money in developing new-to-the-world product. If the required capability for developing a product of required performance by the BOP customers is not far from the existing capability of a firm wishing to develop the product, the developing country firm could take up the challenge to develop the new-to-the-world product. The biggest challenge for the firm would be that the firm does not have adequate experience in developing new-to-the-world product.

Prior literature on the accumulation of technological capability by developing countries shows that, when making a challenge to make new high value added product, firms from developing countries are expected to create new technological capability by acquisition of external resources or by obtaining access to external technical information and support (from foreign technology sources, local firms and consultants, among others) (Katz 1987; Lall 1992, Kim 1980&1997; Liu 2005; Lee et al. 1988; Zhouying ,2005; Zhu and Chen 2006). They also access appropriate "embodied technology" in the form of capital goods (Lall, 1992; Bell and Pavitt 1993; Ernst Mytelka Ganiatos, 1994; Ernst, 1994). The capital goods enable a company to improve efficiency of ‘doing things’ through the capital goods embodying accumulated knowledge of ‘doing things (Rosenberg 1976; Abramobitz 1986). This study shall investigate the above mentioned methods in its exploration of the PD process.

This study explores, through a case study, how the LAPD process is being applied by a firm from a developing country and examines how the firm could implement the LAPD process through the above mentioned methods to complement the weakness of technological capability. This LAPD process could be the process differentiating the process from that in advanced country. At empirical investigation, it was difficult to find a suitable case for this study as it required a case of applying the LAPD process for the BOP market with empirical details. This study found Tata Motors Limited (TML)’s Nano, the world’s cheapest car, as a suitable case. However the product in question had yet to be launched in the market by the time of this study was designed. Therefore, this study focuses on the examination of its business model which are regarded as a successful business model(Johnson et al. 2008); Meredith 2007; Kripalani 2008a & 2008b). In the following section, the framework of investigating an exploratory case is introduced.

2. The framework for investigating LAPD

This study analyzes the LAPD as the PD process within a BOP business model aiming at new market disruption. The concept of a business model adopted here is the one developed by Johnson, Christensen, and Kagermann (2008) which captures the essential features of the model of creating new business. According to Johnson et al., a business model consists of customer value proposition, profit formula, processes and resources which cover the condition of meeting customer demands (customer value proposition), securing profit out of the business (profit formula), the process of doing businesses (processes), and the inputs to the business activities for creating value (resources). In this paper, the discussion on the business model is confined to those relevant to the product development process, especially LAPD.

Table 1 BOP business model aiming at new market disruption-for developing country firm

Factors	**Definition**	**Definition for BOP market for new market disruption**
Customer Value proposition	▪ Value to be achieved for customer satisfaction	▪ Value to be achieved for *low* income customer satisfaction

Profit formula	▪ Revenue model :
	  ▪ How much money can be made?
	  ▪ price x volume
	▪ Cost structure model
	▪ Margin model
		▪ Revenue model :
		  ▪ How much money can be made?
		  ▪ price x volume
		▪ *Low* Cost structure model
		▪ Margin model

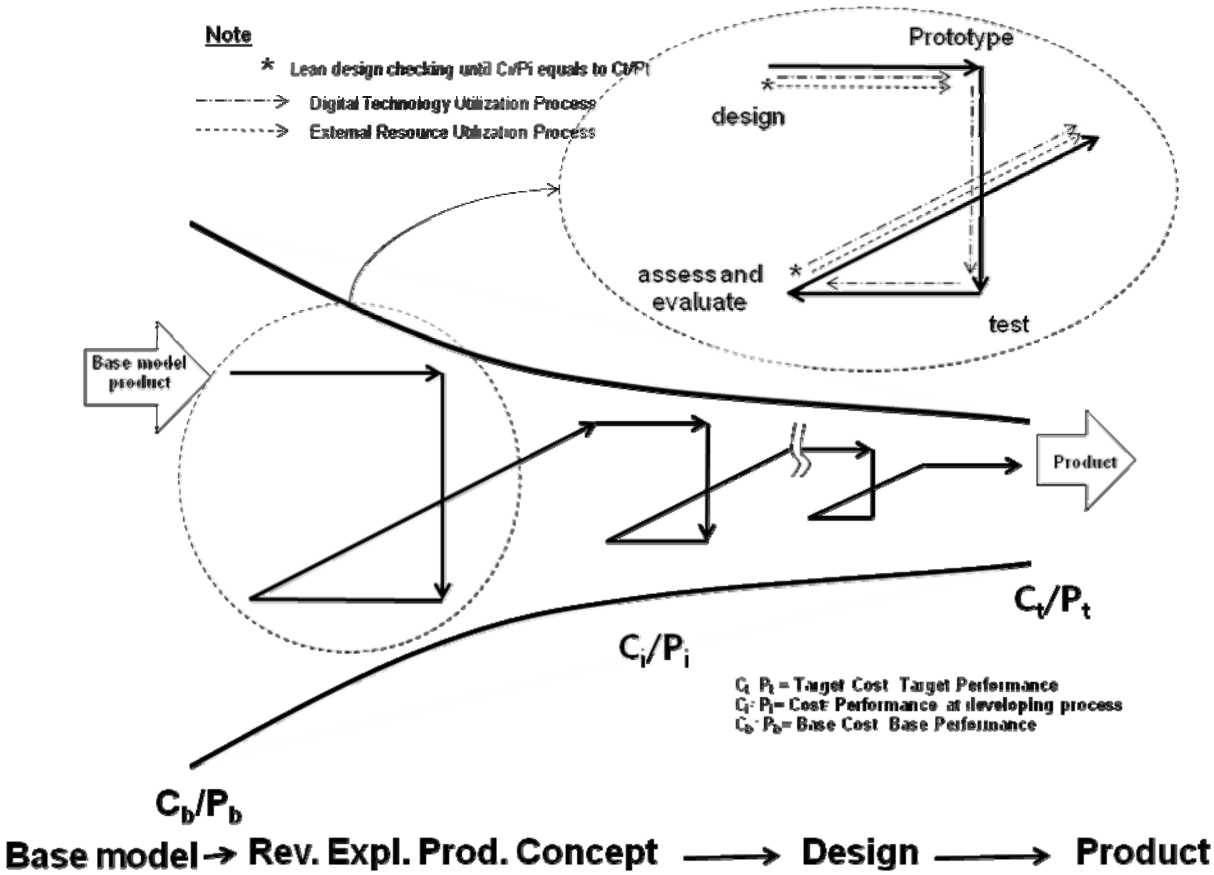
Processes	▪ operational and managerial processes for delivering value: ▪ processes also include a company's rules, metrics, and norms(Christensen,2008)	▪ operational and managerial processes for delivering value - LAPD process to meet customer value proposition at affordable cost - processes of overcoming weaknesses of skills of human resources: processes of utilizing external resources, processes of utilizing digital technology for supporting PD
Resources	▪ People, technology, products, facilities, equipment, channels, and brand required to deliver the value proposition to the targeted customer.	▪ People, technology, products, facilities, equipment, channels, and brand required to deliver the value proposition to the targeted customer. ▪ People lack skills required for PD

The BOP business model aiming at new market disruption is the following. The customer value proposition is the way companies provide value to customers by helping customers to complete an important job(Johnson et al. 2008). The job is a fundamental problem in a given situation(Johnson et al. 2008). The business model has a customer value proposition offering a valuable product to potential BOP customers. The targeted performance for delivering customer value is not as high as the comparable ones in advanced countries. In terms of the profit formula of the model, the business model has the price set to capture a market large enough to generate profit(Johnson et al. 2008). The price needs to be set low enough to provide affordability to low income customers. The cost structure needs to be the low cost structure generating profits in spite of thinner gross margins resulting from low price. This study presumes that the cost structure is shaped in the PD phase which determines the material, components, and architecture of products and the process of manufacturing products. In the model, the operational and managerial processes include marketing and manufacturing processes(Johnson et al. 2008). In this paper, the operational and managerial processes are focused on the PD process because the focus of the analysis is on the LAPD process. The LAPD process in the PD for BOP market, aiming at new market disruption, which can be conjectured from existing literature, is the following: the process of developing products targeted at the BOP customers is not the process of modifying existing products (top down approach)(Prahald 2005, p.48), but the process of developing new-to-the-world product by understanding the characteristics and requirements by the low income customers (bottom up approach).

However the PD process is not the same as making a product from scratch. The PD process is a process making "something in existing market, unaffordable to the BOP customers" affordable to the BOP customers. Therefore the starting point of the PD process is a product already existing but "expensive", thus being required to be "reborn." This product here is called a base model product. Another starting point is a strategic "cheap" price (cost) which would result in a large enough customer-base (Kim & Mauborgne, 1999). Since only a thin margin can be gained from selling a "cheap" product, setting a strategic "cheap" price for securing a large pool of customers that can still generate enough profit becomes important. The price determines the target cost of the product. The process of reducing cost to meet the strategic price needs to be implemented while respecting minimum performance requirements satisfying customer needs.

Given the base model(Cb/Pb) and the target price(cost)(Ct) and the target performance (minimum performance requirements)(Pt), The PD process starts by analyzing an existing base model product for drastic cost reduction. This is a reverse PD process to explore the product concept. After the reverse exploration, a product concept is reached. Then the sequential process of design iteration begins. The PD process follows an iterative process of pursuing target cost and target performance(Ct/Pt). The example of the iterative process could be the one suggested by Thomke and Fujimo (2000). They suggests that the PD process starts from problem recognition and goal definition and undergoes the following iterative steps: (i) design step which is an iterative process of experimental search through the alternatives that are designed (ii) build-prototype-model stage when a prototype of a model is made (iii) test stage when the alternatives are tested against an array of requirements and constraints (iv) analyze and evaluate stage when test outcomes are analyzed and evaluated

Figure 2 the framework on the LAPD process in a developing country firm



For a typical firm from a developing country, there is the LAPD process common to the firm who is weak in technological capability. Employees have the limited experience of developing products. The employees generally lack the skills necessary to implement necessary processes for developing new-to-the-world product such as capturing market demand, exploring and defining product concept, and performing design iterations from basic to final product designs. Therefore the LAPD's process of developing new-to-the-world product includes the process of utilizing external resources and "embodied technology" as have been discussed in the literature session as have been discussed in the literature review.

The most influential "embodied technology" supporting the PD process are the digital technology, which include 3D CAD, CAE, simulations, and product life cycle management(PLM) tools. The technology automates some of the PD process and reduces trials and errors in the PD processes through the visualization and digital simulation and analysis of the impact of design changes. It has been revealed that there has been tremendous progress in the area of the digital technology for the PD process over the last two decades (Baba and Nobeoka, 1998; Dodgson et al., 2005; Thomke & Fujimoto, 2000; Jennifer…).

Therefore, the useful available technology for complementing the weakness of PD capability for firms from developing countries can be the digital technology that can support the PD process. In summary, in the LAPD process for BOP market, aiming at new market disruption, there is a process of designing products pursuing Ct/Pt starting from Cb/Pb and also a process of complementing the weakness of the PD capability through getting access to external sources and also through the use of the digital technology.

3. Research Methodology

This study adopts the case study approach as a research methodology. The case study approach was adopted because the focus of the study is an identification of an exploratory case and building the framework of an explanation of the case. A case study approach can fall into the trap of detailed specificity. In order to overcome this problem, the authors used a framework-case iteration process. The framework was set up as a result of logical conjectures and literature review on the LAPD, disruptive innovation, the BOP business, and the accumulation of technological capability by firms from developing countries.

After an initial framework was established, it was tested for robustness to determine if it could successfully provide a logical explanation of the case. If the framework was not robust enough, it was modified. The framework and the case description had evolved through this framework-case iteration.

The analysis method included analysis of text data which can be divided into two groups. One is the most valuable text which include interviewed sentences that had appeared in the mass media. The interviewed text in the media is accepted as credible data, almost equivalent to direct interviews, as it is presumed that interviewed sentences cannot be released without the consent of interviewees. The other text data are those written by the reporters representing the media. Texts by reporters are regarded as credible only if the text data are concrete enough to reflect an objective situation and if such data can be checked through a comparison with the real data or other reported texts in the media. Other data sources for the study are as in Table 2.

Table 2 Data Sources for the study

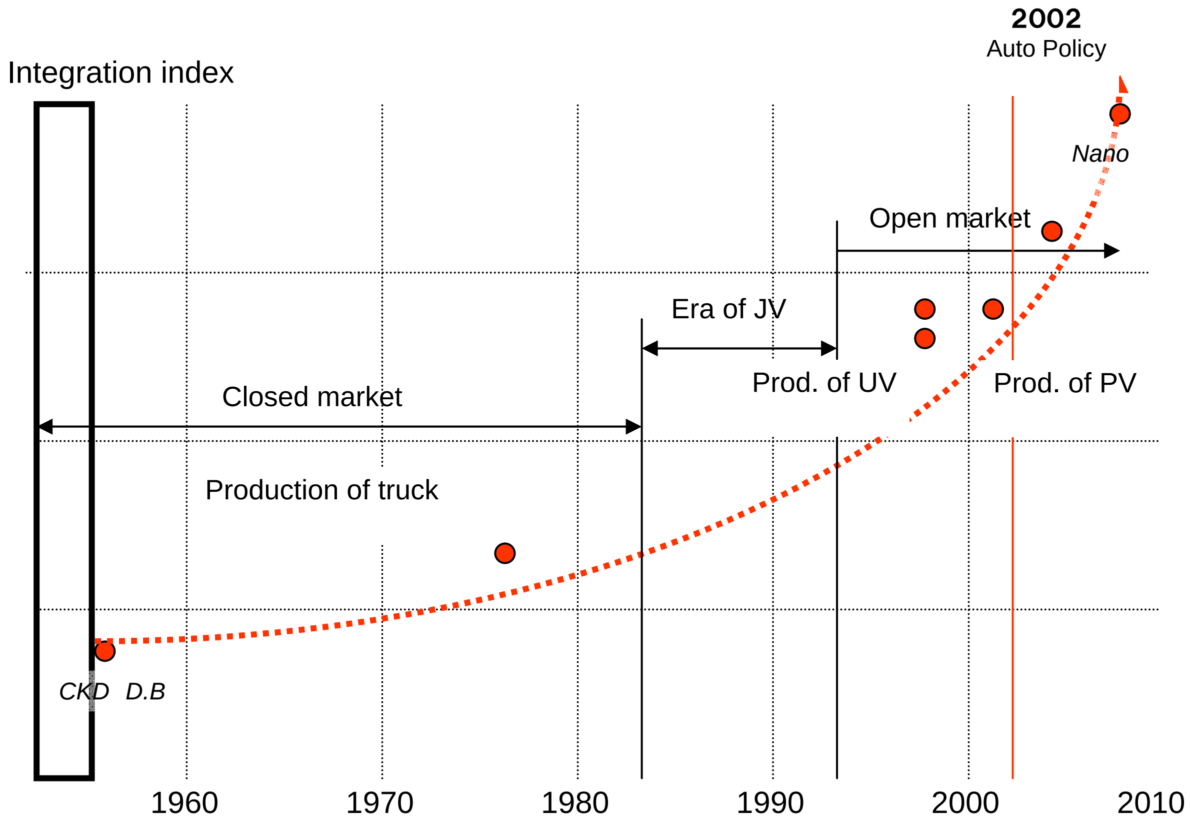
Type of Data	Period for Collection	Location	Major content
Proceeding at conference	Nov. 2006	Japan	Presentation for TML's Digital Engineering Implementation for manufacturing and production
Proceeding at conference	Oct. 2008	USA	TATA Technologies' presentation for TML's digital engineering activities for NANO.
Proceeding at conference	Oct. 2008	Japan	TATA Technologies' presentation for TML's digital engineering activities for NANO.
Interview by E-mail	Oct. 2008~ Jan. 2009	USA & Korea	Lean Design activity contribution for NANO by an USA consulting firm
Survey Interview by E-Mail	Jan. 3, 2009~ Jan. 29, 2009	India	An Engineer from TATA group's consulting company
Document from Internet	Nov. 2008~Jan. 2009	Korea	75 press articles and 6 articles on the CEO available on the company website.
Patent data	Nov. 2008~Jan. 2009	USPTO, WIPO website	Patents granted (US) or data on patents filed (WIPO)
Interview	2003-2007	India	Visit to TML 3 times, Visit to 30 suppliers (2-3 times visit for each supplier)

4. TML history

TML, which was founded in 1945, is currently the largest Auto OEM in India with 22,000 employees and is ranked first in terms of the commercial vehicles market share and second in terms of the passenger car vehicles market share according to Rajuorka et al. (2006). TML produced India’s first indigenous car, INDICA, in 1999 (Rajurkar et al., 2006). It also expanded to a similar series of models such as INDIGO, launched in 2002, and INDIGO Marina in 2004 (Rajurkar et al., 2006). Prior to launching the INDICA, TML also produced Multi Purposed Vehicles (MPV) or Sport Utility Vehicles such as TML SIERRA, TML ESTATE, TML SUMO, and TML SAFARI, all of which were either copied or imitated models of other companies. When the company developed INDIGO, the style design was done by the Institute of Development in Automotive Engineering (IDAE), its engine was purchased from a foreign company, its transmission and body were the result of in-house work partly using other firms’ parts, and the chasis was from originally designed parts. The PD was basically a modified version of foreign products

With NANO, however, the company developed original engine, transmission, body, and chasis, while relying on a style design that was done in part by IDAE. The PD process took four years (2003-2007) with 500 researchers in its engineering research center. The NANO had started selling in July 2009, resulting in 100,000 customers on its waiting list (Nair 2009).

Figure 3: The curve of accumulation of technological capability



Source: Interview of TML.

5. BOP business model aiming at market disruption

Based on the framework discussed, the followings discuss the BOP business model aiming at new market disruption.

5.1 Customer Value proposition

The Customer Value proposition of Tata NANO is offering a safe, four-wheeled vehicle to the BOP customer (e.g., an entire family traveling on a motorcycle). "I observed families riding on two-wheelers, the father driving the scooter, his young kid standing in front of him, his wife …holding a little baby. It led me to wonder whether one could conceive of a safe, affordable, all-weather form of transport for such a family " (Interviewed sentence of Tata Group Chief Ratan Tata in the Indian Express [2008]).

5.2 Revenue model

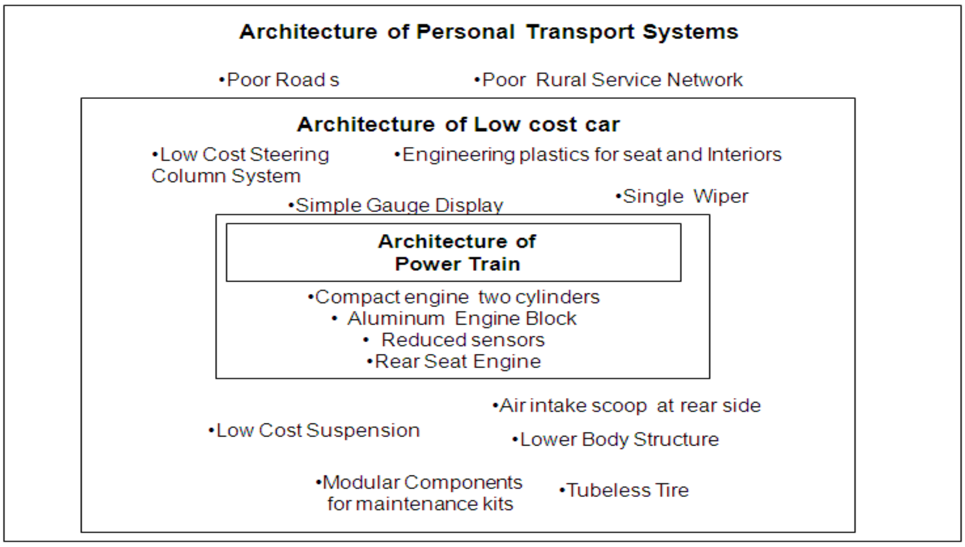
The price of the car at the beginning of the project was set at $2500 (Rs100,000) (Narayanan 2008). The price was set to secure a large enough pool of customers to generate profit. The target customers have been those potential customers who have not been using the car, motor bike riders and three wheeler users.

The car is offered at a price that is roughly 60% more expensive than the most expensive motor bike sold in INDICA and less than half the price of the cheapest car in India. In 2006, 7 million scooters and motorcycles were sold in India, typically for approximately $675 to 1,600 (Meredith, 2007). The car to be offered needed to have a much higher levels of safety, speed, and comfort as compared to motor mikes (Tata Motors, 2008a). In terms of the break even point, the median value of the 6 analysis by livemint.com indicated that the break-even point is 390,000 units per year in terms of earnings before interest, taxes, depreciation, and amortization (Krishnan 2008). Considering that the size of the target market (7 million unit annual sales) and the break even point(390,000 units) of the NANO, the revenue model is based on reasonable conjectures.

Cost structure is can be assumed to be shaped by product design and manufacturing process design. The characteristic feature of the car design is the following. The car is a compact, rear wheel drive car with a 2 cylinder engine with a capacity of 623CC. NANO's product design illustrates how cost reductions can be achieved during the product development stage. The ways NANO achieved cost reductions were through smaller size of the car and components (material cost savings), material substitution (e.g. engineering plastics), 2 cylinder engine, simplified component and design, simplified manufacturing process. The following is the nested system of product architecture that provides a rough picture of NANO's product design (see Figure 4). This aspect is further discussed in the followings.

\

Figure 4 A Nested system of Product Architecture



5.3 Resources

TML was weak in technological capability, especially the product development capability. TML did not have enough resources to develop NANO as the cheapest car in the world. When the project was initiated (as an advanced engineering project) in 2003, the average age of the project team members was between 25 and 30 (Kripalani, 2008). G.A. Wagh, who became the leader of the project team of 500 engineers between 2005 and 2008 was 37 years old in 2008 (TML, 2008b; Agrawal & Wadia, 2008). He was experienced in developing the Ace truck, which began in 2000 and was rolled out in 2005. This indicates that the development team did not possess adequate experience in developing various cars and did not have any experience necessary for the development of new-to-the-world car that would create a new market. Patent data shown in Table 3 clearly imply that TML's human resource was not comparable to other companies.

Table 3 Comparison of US patents granted and PTC patents filed

	TML	Suzuki	Hyundai	Toyota	GM
USPTO	0	599	1358	10,096	10,624

Note: Searched with assignee name "General Motors," "Hyundai Motors," "Toyota Jidosha," and "Suzuki Motors."
Source: Patents granted in the US Patent office(http://www.uspto.gov), accessed on January 8, 2009.

5.4. Processes

This paper limits its process-related discussion to the PD process. The PD process has to be the LAPD in order to reduce cost to the “cheap” level. Because of the weakness in its technological capability, there is a PD process for utilizing external resources and utilization of the digital technology. Further discussions on the process are as in the following section.

6. LAPD process

In 2003, when a project was started as an advanced engineering project, the objective was to develop a car that would be “ultra cheap”. The commercial project for the car was initiated in 2005. The team was given a base model product and the target price of $2500 and minimum requirements of performance. This investigative process was guided by the three parameters given by the CEO: acceptable cost ($2,500 price level), acceptable performance and regulatory compliance (safety and environmental regulation) (Times of India, 2008; Narayanan, 2008). The project was to develop a product similar to Maruti 800. "We took the standard Maruti 800 as the base model and worked backwards on how we can reduce costs.” (interviewed sentences by Ratan Tata-The group Chief [Indian Express 2008]). Given Maruti 800 as the base model, every assumption about its material, design, and manufacturing was questioned in order to drastically reduce its cost.

The LAPD process is initially a reverse process of exploring a given product concept to achieve a drastic reduction in cost while keeping the essential performance. NANO’s initial product concept had ranged from a car made mainly with engineering plastics and raw materials to a four-wheel version of the auto-rickshaw (interviewed sentence of Ratan Tata in Narayanan [2008]). Also considered were a door-less car with a bar as a safety measure and a car with soft doors in vinyl with plastic windows and a cloth roof with two big doors (Agrawal and Wadia 2008). After the concept had been decided, there had been significant design changes which influenced the overall structure and shape of the car. According to G.A. Wagh, "The entire body was designed twice while the engine was designed thrice," before the style of the car was fixed (Gopalan and Mitra (2008). The three parameters were applied to the entire process. With only three parameters to guide them, the engineers kept experiencing failures (Narayanan 2008). Tata Motors’ chief executive Ravi Kant said, "Every day we invite people to come and examine the car and ask: ‘How can we make more savings?’” (Kripalani, 2008).

To explain the process of pursuing Ct/Pt in figure 2, NANO’s engine can serve as an example. In order to reduce the cost of the car, instead of a 4 cylinder engine, the purchase of a 2 cylinder engine by a foreign maker was planned (pursuit of $Ci/Pi \fallingdotseq Ct/Pt$). This plan is rational because the foreign maker has been producing the 2 cylinder engine with economies of scale. But the performance of the purchased 2 cylinder engine was not good enough ($Pi<Pt$). The first engine was a 540 CC engine that, when fitted on the prototype, lacked the necessary power (Kripalani 2008a). Therefore the R&D for improving the 2 cylinder engine was pursued in order to raise its performance ($Pi \geqq Pt$) in 2005, and the team finally succeeded. The number of components such as sparkplugs, piston ring, injector, and engine plug were reduced by using the 2 cylinder engine.

The successful development of the 2 Cylinder engine provided a major momentum in the decision regarding the architecture of the car. After the successful development of the engine, the car’s architecture was shaped as a rear engine car. By placing the engine below the rear seat, a spacious interior space could be secured in spite of the small length of the car ($Pi>Pt$). "The decision to make it a rear engine driven was precisely to reduce the length of the car." (The Indian Express 2008). The reduction in the length of the car reduced the amount of required steel sheet (Ci/Pi reduced). In comparison with a front engine loaded car, a rear mounted engine car would see a reduction in cost for equal speed joint, steering system, and drive shaft joints(removed) (Ci/Pi reduced)(The times of India 2008; Ito 2008). Because of the use of the 2 cylinder engine, there was an R&D needed to develop proper balance shift to reduce vibrations (Ito 2008) (to solve problem of $Pi<Pt$).

The process of reducing cost while maintaining minimum required performance ($Ci/Pi \fallingdotseq Ct/Pt$) can be pursued through design simplification as the above example illustrates. The statement of R. Kant, Managing Director, reflects TML’s design strategy: “The lean design strategy has helped minimize weight.”(Financial Express, 2008). According to N.K. Jain, Deputy General Manager at Engineering Research Centre(ERC) of TML, the company “focused on simple designs and tried to incorporate innovations in that" (Agrawal and Wadia 2008). The elimination of components were made possible by the elimination (and fusion) of various functions. Ito’s report(2008) introduced detailed cases where various components were made unnecessary through the elimination of function, such as air conditioning, power steering, airbags, disc breaks, central lock, power door, and brake booster (Ito 2008). In addition, reductions in components were made through integrated forging (integration of components). For example, 100 units of metal fasteners were reduced (Ito 2008). Ito reported that value engineering and analysis were applied in the reduction of the number of components to reduce cost. Furthermore, the process of reducing cost while maintaining minimum required performance also led to the reduction in the size of components. For example, NANO's steering system is 10 kg, while INDICA's is 15 kg (Ito 2008).

PD activities are stretched to reduce cost in manufacturing. According to V. Suhasrabuddhey, divisional manager, Small Car Project Office, they did an exercise called the design for manufacturing and assembling whereby the design efficiency of each of the assemblies was examined(Agrawal and Wadia, 2008). Some of the car's design, even though the car's design is basically an integral design, was made modular, so that the car could be built and shipped in segments to be assembled in different locations (Hagel and Brown 2008). This also implies that the PD process had considered cost reductions for the manufacturing process. The lean design principle was stretched to vendor management. At an early stage of making a prototype of NANO, Ratan Tata called a meeting of his top parts suppliers and, after showing them the early but flawed prototypes, asked them to help in developing an "ultra cheap" car (Kripalani 2008a). The suppliers participated in developing components with reduced cost at an early stage of product development. It is known that value analysis and value engineering had been diffused to the major suppliers in India (Ito 2008). V. Suhasrabuddhey, divisional manager, Small Car Project Office, mentioned the suppliers' participation in the LAPD: "Basically this means determining how many useful parts there are in the design. We involved the suppliers also in this exercise and they realized that some functions could be integrated in parts. That is how we got some cost benefit" (Interviewed sentence in Agrawal and Wadia[2008]).

The PD process was supported by a foreign lean design consulting company (for further detail, see section 7.2.A). All of the above explains how the LAPD process had been achieved at TML. The following section provides a discussion on how the LAPD process is implemented through reliance on external sources and "embodied technology" for complementing weakness of product development capability.

7 The PD process relying on external sources and "embodied technology"

7.1 PD process relying on external sources I: a world class engineering and design company

The NANO development project was achieved in close cooperation with INCAT. INCAT is an operating company of Tata Technology Limited(TTL). INCAT's services include product design, analysis and production engineering, and product-centric IT services including IT services on the digital tools supporting product development. It has a cooperative relationship with Dassault system, UGS, and Autodesk: companies that provide PD digital technology. Its customers have been the world's premier automotive, aerospace and consumer durable manufacturers (USSEC 2008). The company was a British engineering company until 2005, when it was acquired by Tata group. Its employees number 3000 globally, and it has engineering centers in North America, Europe, India, and Thailand. (USSEC, 2008). INCAT has been involved with the development of the NANO from the start. According to W. Harris, the CEO of INCAT, INCAT had been the "front and center" in the engineering and development of NANO (Interviewed sentence in Teece (2008). INCAT had worked with "a significant number" of NANO's suppliers (Teece 2008). Harris made the following statement: "All of us at INCAT are proud of this historical achievement by our colleagues at Tata Motors, and pleased to have played a part in making it real." (Anand, 2008). Table 4 shows the identifiable case of INCAT's involvement on the NANO project from a newspaper article (Agrawal and Wadia, 2008). DELMIA(digital manufacturing software) user conference presentation by INCAT also shows that INCAT had participated in supporting TML's NANO project in the digital manufacturing software (Khedkar [2008]). Considering that INCAT had been a British engineering company, the involvement of INCAT in the TML NANO project could be regarded as a transfer of technological capability accumulated in advanced countries.

Table 4 The INCAT member participants of the project

Name	Job
N. A Jadhav	Industrial designer who has been working on the project from the inception to the end of the project
RG Rajhans	Project manager, Body Systems Engineering Automation, did simulations for safety testing

Source: Agrawal and Wadia(2008)

This involvement of INCAT was made possible under the support policy at Tata Group level. There has been involvement of human resources of Tata Group in the Tata Motor project. The available text in newspapers supports the Tata group's involvement. Gopalan and Mitra (2008) report that some Tata group companies had provided resources for the NANO project. Talgeri (2008) estimated that the sheer number of automotive engineers and designers in the Tata group had reached about 8,000, including Jaguar's 3,500 engineers (acquired in 2008). This number is already higher than some of the world's largest engineering and design firms, such as the EDAG (5,500 employees) and the Ingenieurgesellschaft Auto und Verkehr GMBH (3,700 employees). The Tata group has made its group companies (Talgeri 2008) transfer skills and cross-pollinate ideas. For instance, an exchange program required 200 Tata Motors engineers from the group's Europe technical centre to work at the Pune center. Talgeri (2008) reported that about 20-30% of these engineers have been staying in India on a full-time basis.

All of this shows that the involvement of INCAT into the Tata NANO's development project was made possible under the strategy of the Tata group for utilization of foreign engineers and designers. All of this reveals that PD process has been implemented with the world class engineering and design company, INCAT, who could complement the weakness in technological capability.

7.2 PD process relying on external sources II: a world class engineering and design company

A. Foreign lean design strategy company

TML had interacted with a U.S. consulting company for applying the LAPD process. The company was involved with TML on the requested designs across the entire design of the car. It provided consulting service analyzing component designs such as engines and the entire interior and achieved a cost reduction of over $***/vehicle. The consulting company emphasizes the lean design strategy reducing cost of total cost by analyzing the impacts of the product design into the total manufacturing costs and reducing low value added designs according to the interview of CEO and the company's web site and the CEO's short article (Interview on June 2 of 2009).

B. Supplier

TML had relied on competent independent suppliers, including multinational corporations, who have had rich experience working in India and with domestic companies for the cooperative development of components(see the following table for the list of suppoiers participated in the cooperative development project. As have been discussed above, they had been involved in developing cost-reduced-components since the early stages of the product development.

Table 5 Suppliers involved in the PD project

External suppliers	Business Field	Components	Services	Source
TTL INCAT*	Consulting	N/A	PLM, Product Design and Engineering	Agrawal and Wadia (2008), Anand (2008)
Dassault Systemes (French) and SIEMENS PLM (German)	Software and consulting	N/A	PLM, Digital Innovation Technology, Industrial Knowledge	Mitra (2008)
Bosch (German)	Component maker	Engine's Multi-point fuelling systems and also electronic management systems	N/A	The Times of India (2008)
Rane Group (Indian?)	Component maker	Steering, gears, columns, and seat belts	N/A	Economic Times (2008 b)
Italy's Institute of Development	Styling Design	N/A	Styling	Tata (2008), Narayanan (2008)
US Consulting Company	Lean design Consulting	N/A	Lean Design and Engineering	Interview
Sona Koyo(German) and Rane Group	Component maker	hollow steering shafts	N/A	Narayanan (2008)
Emcon technologies (US)	Component maker	exhaust system	N/A	Narayanan (2008) Gopalan and Mitra (2008)
MRF Tyres (Indian)	Component maker	tyres to bear extra weight on rear wheels	N/A	
Lumax Lighting (US)	Component maker	tail light fixtures	N/A	
GKN (UK)	Component maker	Driveshafts	N/A	The Times of India (2008)

Note: 1 *Tata group firm,
2 ( ) country of origin of the company

The number of direct suppliers was confined to 100, and Tata relied on these 100 companies for managing the second and third level suppliers in the reduction of component cost (Ito 2008). According to the interview result of suppliers, the share of components outsourced are estimated to be around 85 % in terms of the cost of components.

7.3 Utilizing "embodied technology": the digital technology.

According to its company report, TML has a strategy of active utilization of the digital technology that supports the PD process. TML's annual report to the United States Securities and Exchange Commission (USSEC 2008, p. 20) states the following: "we have aligned our end-to-end digital PD objectives… with our business goals and have made significant investments to enhance the digital PD capabilities especially in the areas of PD through Computer Aided Design(CAD)/Computer Aided Manufacturing(CAE)/Computer Aided Engineering(CAE)/Knowledge Based Engineering/Product Data Management.” The report further states that the ERC is “equipped with computer-aided design, manufacture and engineering tools, designed to create a digital PD environment and virtual testing and validation.” The digital technology used by TML made it possible for TML to design with 3 D CAD, build prototype digitally, perform certain tests including simulations, and evaluation results. To take an example of the digital technology, 3 D CAD designing is implemented with CATIA, digital prototyping with CATIA, and simulations and validation of designs with DELMIA. According to an engineer from a consulting company that had advised Tata on the use of the digital technology(email interview on 15 January, 2009), NANO is more advanced than INDICA or INDIGO in terms of CAE, digital mockup, digital validation for final assembly, digital validation for body, and digital factory modeling.

The identifiable texts on Tata’s use of the digital technology are as the following. Testing had been made possible with the digital technology. Rajurkar, General Manager of Technology & Production Services, made the following statement: “Earlier, only after we had made prototypes did we realize that we had overlooked some practical problems. … But it was too late to do anything then. Now, we are able to figure out such problems at the desktop and take corrective measures.” According to Rajurkar, this simulation saved “a large number of prototypes” in the testing of new products(Interviewed sentence in Trivedi[2008]). According to T.N. Umamaheshwaran, CTO(engineering automation, “We can’t imagine what would take place at a new plant, if we did not have DM[digital manufacturing] tools. Two years before the first stone of a plant is laid, we already start working on it…. You can simulate all the operations even before the first of machines are installed” (interviewed sentences in Trivedi[2008]).

All of the above discussions shows that the digital technology was used in the design iteration process of the LAPD: design-building prototype-test stage work has been supported by the digital technology. All of the discussions in section 7.3 show that the PD process in TML’s NANO development was supported by the digital technology under the strategy of utilization of the digital tools.

8. Conclusion

This study explores the LAPD in the context of developing countries. Although it might seem too early to apply the LAPD approach, which is at an early stage of adoption even in advanced countries, into the PD process in developing countries, there is one area where this approach may be appropriate. That is the PD for the BOP market, aiming at new market disruption.

The BOP market calls for a bottom up approach in delivering “new the world” products or services, respecting the value and affordability condition of the BOP customers. For a firm from a developing country, developing an original product for the BOP market using a bottom up approach may be unreachable due to its currently weak PD capability. This study explores how the lean principle applied the PD process has worked in developing countries and how this is being made possible in spite of the weakness in PD capabilities.

The PD process starts from a base model, an existing available product which is ”expensive” and which needs to be “reborn” to be made affordable to the BOP customers. Starting from a target price and target performance(minimum performance requirements) that are acceptable to the BOP customers, the process undergoes a reverse exploratory process of fixing product concept, achieving a drastic cost reduction. Then, through sequential design iterations that take a fixed product concept to the final product, the target cost and performance can be achieved. Because the BOP customers do not require their products to be as sophisticated as the ones offered in advanced countries, firms from developing countries can focus on developing original products for the BOP market in spite of their weak PD capabilities. In order to complement their weakness, the BOP firms can utilize external sources of knowledge and the digital technology that supports the PD process.

The case study’s result shows that the LAPD process for the BOM market was found in the automobile industry, where sophisticated technological capability is required. The result implies that the LAPD could be applied to other industries that require a similar, or lower, level of technological capabilities in PD activities.

This study contributes to the discussion on the BOP business model and disruptive innovation in that it provides a framework for explaining how a firm from a developing country could develop products for the BOP market, aiming at new market disruption, despite their relative weakness in PD capability.

This study also contributes to the discussion on the theory of technology catch-up of developing countries. Most of the technology-oriented views explaining how developing countries catch up with advanced countries focus on how they assimilate and adapt technologies from advanced countries (Bae, 1997; L. Kim, 1980; Lee et al.,1988; Utterback & Abernathy, 1975; Vernon, 1966; Lall, 1992, 1998) and how they actively utilize emerging technological opportunities from abroad (Mathews, 2001, 2002, 2003; Yusuf, 2003; Lee & Lim, 2001). A common view held by these studies is that the firms from developing countries shift from imitating foreign goods to developing a new-to-the-world product as their technological capabilities are accumulated. An ability to develop the new-to-the-world product implies an ability to develop products that can be sold in advanced countries. If a company builds a capability to develop the original product, the company has the technological capability necessary to become a global player. This study suggests another category of new-to-the-world product. This refers to the original product for the BOP market that can cause new market disruption. Because the performance of the product required for BOP market does not have to be as sophisticated product as the one offered in advanced countries, a developing country firm can make a challenge to develop new-to-the-world product for the BOP market, even if they lack fully developed PD capability, even though the company needs to find the ways to complement the weakness of the capability. As TML is expected to advance their technological capability through both developing products for BOP markets and products for non-BOP markets, the developing country firm can now have another path of accumulating technological capability: developing new-to-the-world products for BOP market. Further research on this topic is warranted to shed additional light on the theory of technology catch up and the strategies employed by the firms to close technological gaps with their counterparts in advanced countries.

This study is an exploratory case study examining an innovative new-to-the-world product development case. Therefore the analysis is confined to one case. However the conclusion drawn out of one case can be a misleading one. Tata Motors' NANO may have some exceptional unique features. For example, TML's NANO PD process was supported in part by INCAT and presumably some other firms under the Tata Goup. However, TML was the focus on this study. The Tata group can be an exceptional group that has acquired excellent global standard design and engineering resources within the group. It may be difficult for other firms in developing countries to obtain access to highly qualified human resources such as INCAT without the support of a large conglomerate like the Tata Group. As such, additional developing country case studies on the LAPD process for the BOP market may be needed to corroborate the finding of this study. In addition, this study had not investigated the organizational capability of TML in explaining the LAPD process for the BOP market as new market disruption. In TML's challenge to develop a new-to-the-world product, there could have been immense changes in processes and organizational structures and features. The empirical research on this aspect is expected to reveal further progressive results on management of LAPD for BOM market, aiming at new market disruption.

Acknowledgement

Authors are grateful for the comments during KOSIME conference at Jeju on June 2009 and JAFEE at Okayama University on April 2009. They are also grateful to Professor Takahiro Fujimoto at Tokyo University and Jidae Kim at Chungnam University for insightful comments.

Reference

Abramobitz, M. (1986) 'Catching up, forging ahead and falling behind,' *Journal of Economic History*, Vol.XLVI, No.2.

Albert, M. (1998). *The New Innovators: Global patenting trends in five sectors*, Office of Technology Policy, U.S. Department of Commerce

Agrawal, S. and Wadia, J. (2008) 'Tata Nano: the Big wonder,' *http://tatanano.inservices.tatamotors.com/tatamotors/index.php?option=com_content&task=view&id=184&Itemid=210&limit=1&limitstart=0 (accessed in Dec. 20, 2008)*

Allen, C.W. (2007) 'Lean Product and Process Development' Cambridge, MA: Lean Enterprise Institute, 2007.

Amsden, A. (1989) *Asia's Next Giant: South Korea and Late Industrialization*, Oxford Univ. Press, Oxford

Amsden, A.H. and W.-W. Chu (2003), *Beyond Late Development: Taiwan's Upgrading Policies*, Cambridge, MA: The MIT Press.

Anand (2008) 'INCAT Congratulates Tata Motors on Nano Introduction' March 14, 2008, *http://machinist.in/index.php?option=com_content&task=view&id=1055&Itemid=2 accessed in January 20, 2009*

Anderson,D.M.(2006) *Design for manufacturability & concurrent engineering: how to design for low cost, design in high quality, design for lean manufacture, and design quickly for fast production*, Cambria, Calif. : CIM Press

Baba, Y. and Nobeoka, K.(1998) 'Towards knowledge-based PRODUCT DEVELOPMENT: the 3-D CAD model of knowledge creation,' *Research Policy* Volume 26, Issue 6, February, pp. 643-659

Bae, Y.H. (1997) 'Development of Technological Capability in the Semiconductor Industry,' in Lee, K. et al. (eds.), *Technological Capability and Competitiveness of Korean Industries*, pp. 169-214, Seoul: Kyung-moon-sa (In Korean)

Baines, T.; Lightfoot, H.; Williams, G.M.; R. Greenough (2006) 'State-of-the-art in lean design engineering: a literature review on white collar lean Proceedings of the Institution of Mechanical Engineers,' *Journal of Engineering Manufacture*, Volume 220, Number 9, pp. 1539-1547

Ballard, G. and Koskela, L. (1998) 'On the agenda of design management research.' *Proceedings on the 6th Annual Conference International Group for Lean Construction*, International Group for Lean Construction,

Bell, M. and K. Pavitt(1992) 'Accumulating technological capability in developing countries' In Proceedings of the World Bank Annual Conference on Development Economics, 1992, Washington D.C.: World Bank.

Braha, D. and O. Maimon (1997), The design process: Properties, paradigms, and structure, *IEEE Transactions on System, Man and Cybernetics* 27(2), pp. 146–166.

Breznitz, D. (2005), 'Innovation and the limit of state power: integrated circuit design and software in Taiwan', in S. Berger and R.K. Lester (eds), *Global Taiwan: Building Competitive Strengths in a New International Economy*, Armonk, NY: M.E. Sharpe, pp. 194–227.

Browning, T.R. (2003) 'On customer value and improvement in product development process,' *Systems*

Engineering, Vol.6 No.1, pp. 49-61.
Bukoveczky, E. (2008) ‘Tata's Nano A Big Deal (TTM),’ *Investopedia, Jan. 14,2008,* *http://research.investopedia.com/news/IA/2008/Tatas_Nano_A_Big_Deal_TTM.aspx?ad=IA_RSS_1142008&partner=fincon-rss* (accessed 15 Dec. 2008).
Business Standard (2008) ‘World's cheapest car is here, finally,’ *January 11, 2008*
Chase, J. (2000*) ‘Measuring value in Product Development, The Lean Aerospace Initiative,’* Massachusetts Institute of Technology
Christensen M.C. (1997) *The Innovator's Dilemma : when new technologies cause great firms to fail,* Harvard Business School Publishing Co.
Christensen, M. C. and Raynor, F. M. (2003) *The innovator's solution: creating and sustaining successful growth,* Harvard Business School Publishing Co.
Christensen, M.C., Crsig, T. and S. Hart (2001) ‘The Great Disruption,’ *Foreign Affairs*, March/April, pp. 80-95
Clark, KB; Fujimoto, T. (1991) *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry,* Harvard Business School Press
Collins, S. and B. Bosworth (1996), ‘Economic growth in East Asia: accumulation versus assimilation’, *Brookings Papers in Economic Activity*, **2**, 135–204.
Crazy Engineers(2008) ‘Small Talk with Mr. Girish Wagh-Realizing The Big Small Car Dream,’ *http://www.crazyengineers.com/small-talk/1-cover-story/65-small-talk-with-mr-girish-wagh-realizing-the-big-qsmall-carq-dream (accessed in Jan. 14), 2009*
Dahlman et al., (1985) ‘Reflections on acquisition of technological capability,’ . *In:* Rosenberg, N. and Frischtak, C., Editors, 1985. *International Technology Transfer: Concepts, Measures and Comparisons*, Pergamon, New York.
Dodgson, Mark; Gann, David; Salter, Ammon (2005) *Think, Play, Do: Technology, Innovation, and Organization,* Oxford University Press
The Economic Times (2008 a) ‘Designer Girish Wagh: The Whizkid who shaped Tata Nano,’ January 12th, 2008.) *http://economictimes.indiatimes.com/articleshow, accessed in 2008. 12. 20.*
The Economic Times (2008 b) ‘Tata Nano: Mass hysteria leaves vendors beaming,’ January 12.
Financial Express (2008) ‘Nano indeed will meet a genuine need of thousands of our families’, *Financial Express* , April 7th, 2008.
Ernst (1994), ‘Network transactions, market structure and technology diffusion-implications for South-South cooperation’ in Lynn Mytelka ed. OECD Development Centre Documents, Paris. ,
Ernst,D. and D. O’Conner (1989) ‘Technology and global competition, The challenge for newly industrializing economies,’ OECD Development Centre Studies.
Ernt, D. and L. Mytelka and T. Ganiatos (1994) ‘Chapter 1 Technological capabilities,’ *UNCTAD Six-Country Research Project Report*, UNCTAD.
Freire, J. and L.F. Alarcon (2002) ‘Achieving Lean Design Process,’ *Journal of Construction Engineering and Management*, May-June.
Gerschenkron, A. (1963) ‘The Early Phases of Industrialization in Russia: Afterthoughts and Counterthoughts’ *The Economics of Take-off into Sustained Growth*, London: Macmillan.
Gopalan, K. and K. Mitra (2008) ‘How Nano was built,*’ Business Today*, January 22, 2008 *http://businesstoday.digitaltoday.in/ accessed in Oct. 12, 2008*
Gupta, I. and R. Sriram (2008) ‘Interview with Ratan Tata: Making of Nano,’ *Economic Times, January 11th, 2008 http://economictimes.indiatimes.com/Interview_with_Ratan_Tata_Making_of_Nano/articleshow/2690794.cms (accessed in Jan. 15,2009).*
Hagel,J. and Brown, JS (2008) ‘Learning from Tata's Nano,’ *Business Week*, Feb. 28.2008
Haque, B. (2003) ‘Lean engineering in the aerospace industry,’ *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* Volume 217, B10, 2003, 1409-1420.
The Hindu Business Line (2008) ‘Taking the common man to Nano-sphere,’ *January 13, 2008. http://www.thehindubusinessline.com/iw/2008/01/13/stories/2008011351331700.htm*
Hobday, M. (1995) *Innovation in East Asia the Challenge to Japan,* Cheltenham:Edward Elgar.
Hoffman, K. (1989) ‘Technological advance and organizational innovation in the engineering industry.’ *Industry and Energy Department Working Paper, Industry Series Paper* No. 4, Washington, DC: World Bank.
Hung, S.-C. (2002), ‘On the co-evolution of technologies and institutions: a comparison of Taiwanese hard disk drive and

liquid crystal display industries', *R&D Management*, **32**(3), 179–90.
The Indian Express (2008), 'Little Nano, the next big thing 20 km per litre; 21% more space than Maruti 800; Bharat III emission norms', January 11th, 2008
India Today (2008) 'Ratan's revolution' January 11, 2008.
Ito, H. (2008) 'The India's own cost reduction method started from Tata Nano,' *Fourin* August (Japanese). ,
Johnson, Christensen and Kagermann (2008) 'Reinventing your business model' *Harvard Business Review,* Dec 2008, Vol. 86 , pp.50-59.
Karlsson and Ahlstrom (1996) 'The difficult path to learn product development' *Journal of Product Innovation Management*, Vol. 13, pp.283-295.
Katz, J. (1987) '*Technology Generation in Latin American' Manufacturing Industries,* London: Macmillan.
Khedkar,G. (2008) 'Case Study-The Tata/DELMIA Story: A Digital Manufacturing Success,' *Proceeding at DELMIA North America User Conference*, Oct. 8, 2008 in Detroit, MI, USA.
Kim, L. (1980) 'Stages of development of industrial technology in a developing country: a model', *Research Policy*, Vol. 9, No. 3, pp.254-277.
Kim, L. (1997) *Limitation to Innovation : the Dynamics of Korea's Technological Learning,* Boston:Harvard Business School Press,
Kim, W.C. and R.A. Mauborgne (1999) 'Creative New Market Space,' *Harvard Business Review*, Jan/Feb, 1999
Kim, W.C. and R.A. Mauborgne (2000) *Knowing a winning business idea when you see one,* Harvard Business Review, September-October.
Kripalani, M. (2008a) 'The story behind the Nano,' *Business Week,* May 9th, 2008
Kripalani, M. (2008b) 'Inside the Tata Nano Factory,' *Business Week,* May 9, 2008,
Krishnan, R. (2008) 'Tata needs to sell 30,000 Nanos a month,' *Live Mint.com,*
http://www.livemint.com/2008/07/22000207/Tata-needs-to-sell-30000-Nano.html, Jul. 22, 2008
Kumar, N. (2006) 'Strategies to fight low-cost rivals,' *Harvard Business Review*, Vol. 84 No.12, pp.104-12.
Lall, S. (1992) 'Technological capabilities and industrialisation,' *World Development*, 20, pp. 165-186.
Lall, S. (1998) 'Technological capabilities in emerging Asia,' *Oxford Development Studies,* Vol. 26 Issue 2, pp. 213-244.
Lee, J., Bae, Z. and Choi, D. (1988) 'Technology development processes: a model for a developing country with a global perspective', *R&D Management*, Vol. 18, No. 3, pp.235-250.
Lee, K. and C. Lim(2001) 'Technological Regimes, Catch-up and Leapfrogging: Findings from the Korean Industries,' *Research Policy* 30, pp. 459-483
Lee, K., Lim, C. and W. Song (2005) 'Emerging Digital Technology as a Window of Opportunity and Technological Leapfrogging: Catch-up in Digital TV by the Korean Firms,' *International Journal of Technology Management*, Vol. 29, Nos. 1/2, pp.40-63.
Liu, X. (2005) 'China's Development Model: An Alternative Strategy for Technological Catch-Up,' *Working paper*, Institute of Innovation Research Hitotsubashi University.
Major, F. and R. Gibbels. (2006) *Collaboration Aids Innovation Offshore Global*, Offshore Report, www.eandpnet.com
Malerba, F. (2004) *Sectoral Systems of Innovation,* Cambridge University Press, Cambridge.
Mascitelli, R. (2005) *The Lean Design Guidebook: Everything Your Product Development Team Needs to Slash Manufacturing Cost*, Powell Books, USA.
Mathews, J.A. (2005), 'Strategy and the crystal cycle', *California Management Review*, **47**(2), 6–32.
Meredith, R.(2007) 'The Next People's Car,' *Forbes, 16 April 2007.*
http://www.forbes.com/business/forbes/2007/0416/070_2.html
Miles, LD (1989) *The text, Techniques of Value Analysis and Engineering,* 3rd edition, the Wendt Library, (First edition published in 1961)
Miller, L., Miller, R. and J. Dismukes (2005/2006) 'The Critical Role of Information and Information Technology in Future Accelerated Radical Innovation,' *Information Knowledge Systems Management,* 5, pp. 63-99.
Mitra, M. (2008) 'Always something new- 3D and business,' *Nov. 28, 2008, The Economic Times,*
http://economictimes.indiatimes.com/ *accessed in Jan. 4, 2009*
Moneycontrol.com (2008) 'Rs 1700 cr invested to manufacture Nano: Ravi Kant,' *Jan 11, 2008.*
Mu, Q. and K. Lee (2005) Knowledge diffusion, market segmentation and technological catch-up: The case of

the telecommunication industry in China, *Research Policy*, Volume 34, Issue 6, August 2005, Pages 759-783
Munro & Associates Inc.(2008), Company Brochure, Munro & Associates Inc.
Munro, S. (1999), " Lean Manufacturing starts with Lean Design," *Automotive Manufacturing & Production,* P. 27.
Muralidhar S. (2008) 'Taking the common man to Nano-sphere,' *Hindu Business Line, January 13, 2008.*
Narayanan, D. (2008) 'The making of a modern classic,' *Businessworld, 22 January - January 28, 2008, http://www.businessworld.in/index.php/Automobiles/The-Making-Of-A-Modern-Classic/Page-6.html accessed in Jan. 4, 2009.*
Nelson, R.(1992) 'National innovation systems : a retrospective on a study,' *Industrial and Corporate Change*, 1, pp.347-74.
Nightingale, P.(2000) 'The product-process-organisation relationship in complex development projects' Research Policy 2000, Vol. 29, pp.913–930.
Nair, V. (2009) 'Tata Motors Delivers First Nano, World's Cheapest Car,' Bloomberg.Com, July 17 http://www.bloomberg.com/apps/news?pid=20601091&sid=a1qgauL1lnU8 Accessed in 30 Aug, 2009.
O'Connor, A. (2008) 'Tata Nano - world's cheapest new car is unveiled in India,' *The Times http://www.timesonline.co.uk/tol/driving/article3164205.ece January 11, 2008*
OECD (1981), *The Measurement of Scientific and Technical Activities: proposed standard practice for surveys of research and experimental development, OECD*, Paris, p. 15
OECD (1992) *Technology and Economy: The Key Relationships*, OECD, Paris
Perez, C., Soete, L. (1988) *Catching-up in technology: entry barriers and windows of opportunity, Technical Change and Economic Theory.* Pinter Publishers, London
Porter, M. (1990) *The Competitive Advantage of Nations*, Free Press, New York.
Rahman, A. (2008) 'Low cost car,' September 23, 2008 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1272355 accessed in 10 March 2009.
Rajurkar, N., Khedkar, G. and Y. Deo(2006) 'Implementation of DELMIA Solution in TATA MOTORS,' *Proceeding at Asia Pacific User Conference 2006*, Yokohama, Japan.
Reinertsen, D. (1998) 'Testing: Annoyance or opportunity' *Electron Design*, November 1998, Vol. 46, pg.64H.
Rothwell, R. (1992), 'Developments towards the fifth generation model of innovation. Technology,' *Analysis and Strategic Management*, 4(1), pp. 73-75.
Sandberg, B. (2002) 'Creating the market for disruptive innovation: Market proactiveness at the launch stage,' *Journal of Targeting, Measurement and Analysis for Marketing*, Vol. 11, 2, pp. 184-196
Sawai, M.(1987) 'Chapter 9, Multi-layered development of machine tool industry: with a focus on the 1920s." In *Japanese Industrialisation and Technological Progress*, edited by R. Minami and Y. Kiyokawa. Tokyo: Toyo Keizai Shinpo-sa, 1987 (Japanese).
Schrage, M. (2000) *Serious Play*, Harvard Business School Press.
Singh, S. (2008) 'The man and his dream machine,' *Indian Express, January 12th, 2008. http://www.indianexpress.com/news/the-man-and-his-dream-machine*
Talgeri, KN (2008) 'The transformers,' *Nov. 01, 2008 Outlook business*
Tata Motors Limited (TML) (2008a) 'Ratan Tata's speech at the unveiling ceremony of the Nano,' *http://tatanano.inservices.tatamotors.com/tatamotors/index.php?option=com_content&task=view&id=143&Itemid=169 accessed in 2009, 0107*
Tata Motors Limited (TML) (2008b) 'How Nano was built,' *http://tatanano.inservices.tatamotors.com/tatamotors/index.php?option=com_content&task=view&id=215&Itemid=207 accessed in 2009, 0105*
Tata Motors Limited (TML) (2008c.) http://tatanano.inservices.tatamotors.com
Teece, D. J., Pisano, G., and Shuen, A. (1997), Dynamic capabilities and strategic management. *Strategic Management Journal* 18(7), pp. 509-533
The Times of India (2008) *'Engineering The Nano,' January 11th, 2008.*
Thomke, S. (2001) '*Enlightened Experimentation: The New Imperative for Innovation,' Harvard Business Review 2001, Vol.* 79(2), pp.67–75.
Thomke, S. (2003) *Experimentation Matters*, Harvard Business School Press
Thomke, S. and Bell, D. (1999) *Optimal testing in product development*, Harvard Business School 1999

Thomke, S. and T. Fujimoto (2000) ‘The Effect of Front Loading Problem Solving on Product Development Perfarmance,’ *Journal of Product Innovation Management.* pp. 128-142

Teece, JB. (2008), Automotive News, Nano brings credibility to Indian engineering, 2008, April 14.

Trivedi, G. (2008) ‘Driving Down Cost,’ *CIO India,* Feb 6, 2008. http://www.cio.in/ accessed in 2008. 12.09.

United States Securities and Exchange Commission(USSEC) (2008) Annual Report Pursuant To Section 13 or 15(d) of the securities exchange act of 1934 Sixty-third annual report 2007-08 (For the fiscal year ended March 31 2008), TATA MOTORS

Utterback, J.M. and Abernathy, W.J. (1975) ‘A dynamic model of process and product innovation’, *Omega*, Vol. 3, No. 6, pp.640-656.

Vaitheeswaran, V. (2008) ‘Something new under the sun-a special report on innovation,’ *Economist*, October 13th 2007.

Vernon, R.(1966) International investment and international trade in the product cycle. *Quarterly Journal of Economics* 80, pp.190-207.

Wheelwright, SC. and Kim B. Clark (1992) *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality,* Free Press, Research on the Management of Innovation, Oxford University Press.

Winter, S.G. "8. Knowledge and competence as strategic assets." In *The Competitive Challenge*, edited by D. J. Teece. : Ballinger Publishing, 1987.

Womack, J. P. and Jones, D. T. (1996) ‘Lean Thinking: Banish Waste and Create Wealth in Your Corporation.’ New York: Simon & Shuster.

Wong, P.K., M. Kiese, A. Singh and F. Wong (2003), ‘Pattern of innovation in the manufacturing sector of Singapore’, *Singapore Management Review*, **25**(1), 1–34.

World Bank (1993) *The East Asian Miracle: Economic growth and Public Policy,* Oxford Univ. Press, New York.

Zhouying ,J. (2005) ‘Globalization, technological competitiveness and the ‘catch-up’ challenge for developing countries: some lessons of experience,’ *International Journal of Technology Management and Sustainable Development,* Volume 4, No. 1

Zhu, Z., Chen, J. (2006) “Open Innovation and Technological Learning in China”, *Proceedings of Engineering Management Conference, IEEE International.*