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New trends in Flexible Manufacturing technologies: A Case study of Toyota's Lean Manufacturing System

Prof. Niraj Kumar
Center for Technology Policy, Apeejay Stya University, Gurgaon, INDIA

Abstract: Flexible Manufacturing system and design is an emerging area in management of technology across Organizations and Business in the manufacturing and services sector, addressing the need of the industry on Flexible Manufacturing for the Micro Small and Medium Enterprises to meet their strategic objectives and apply business process management approach to implement this emerging technology. An overview is provided of different types of new manufacturing technologies which are flexible in their domain and impacts Business value creation. Toyota's lean manufacturing case study substantiates this paper.

Keywords: Flexible Manufacturing system, Management of technology.

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1. Introduction

Lean Manufacturing: What the industries require

Today when we talk about manufacturing we are not just limited to final products/ goods which would be produced but our boundaries to understand the term Manufacturing has increased by many folds. Although the final product out of the manufacturing procedure is what we require but, we have started to lay emphasis on the related aspects of manufacturing with which we can ensure effectiveness and efficiency. And with the advent of this scenario traditional manufacturing practices have been left behind and are obsolete now. Gone by the days when Manufacturing Procedures were known only for Production, now it has been emerged as the most critical asset to be handled in an organization. Getting right manufacturing technique and practice is only one side of the coin but to explore its capability and tap the areas where savings in terms of both finances and production time can be incurred is of the utmost importance. From mid 1960s, market competition has become much more grim and intense and sustenance of an organization has turned out to be a herculean task keeping in mind the competitors. Earlier, cost was a major concern after which Quality became a priority. Complexity in the market gave rise to speed of delivery. And to ensure speed of delivery with an appropriate level of quality and keeping in mind the cost factor, the only thing which could be improvised was be the manufacturing practice. This paradigm shift gave rise to practice of Flexible Manufacturing System(FMS) , a manufacturing system in which there is some amount of flexibility to react in the case of changes, whether predicted or unpredicted. , (A. de Toni and S. Tonchia) which includes machine flexibility and routing flexibility

2. New Trends in Manufacturing System Design - A comparison and Development on the Technological Front

An Industrial Flexible Manufacturing System (FMS) comprises of robots, Computer-controlled Machines, Numerical controlled machines (CNC), instrumentation gadgets, workstations, sensors, and other remain solitary frameworks, for example, review machines. The utilization of robots in the preparation section of assembling businesses guarantees a mixed bag of profits extending from high usage to high volume of productivity. Every Robotic cell or hub will be spotted along a material taking care of framework, for example, a transport or programmed guided vehicle. The processing of each one part or work-piece will oblige an alternate blending of assembling hubs. The development of parts starting with one hub then onto the next is carried out through the material taking care of framework. At the end of part handling, the completed parts will be directed to a programmed examination hub, and hence emptied from the Flexible Manufacturing System. Flexible Manufacturing is the total conversion of the traditional Manufacturing Process into a Robot governed/ controlled Mechanism. The development now has also given a new practice of feedback mechanism through the final product which is produced. Executive software's are being used for the exchange of information and messages for Machining Data, instrument to instrument Communication, Status Monitoring, and Data Reporting is transmitted in small size. A Token Bus is a network which administers Token Ring, a local area network (LAN Technology) protocol residing at the Data Link Layer (DLL). It uses a special three bite frame called a token that travels around the ring. In practice, there are different types of FMS which are existing. (Askin R. G., and Standridge) . There are many kinds of flexibility and indeed a sizable literature devoted to competing typologies of the various kinds of flexibility (see overview by Sethi and Sethi 1990). However, from an organizational point of view, all forms of flexibility present a common challenge: efficiency requires a bureaucratic form of organization with high levels of standardization, formalization, specialization, hierarchy, and staffs; but these features of bureaucracy impede the fluid process of mutual adjustment required for flexibility; and organizations therefore confront a trade off between efficiency and flexibility (Knott 1996,Kurke 1988).

Table 1.0 Flexible manufacturing system Categorization:

FMS Division in terms of	**Division 1**	**Division 2**
Operation	**Processing operation:** transforms a work material from one state to another	**Assembly operation:** joining of two or more component to create a new entity
Operational Machines (Count)	**Single machine cell:**fully automated machine capable of unattended operations for a time period longer than one machine cycle	**Flexible manufacturing cell:** two or three processing workstation and a part handling Processing operation
Flexibility:	**Dedicated FMS:** produce a particular variety of part styles	**Random order FMS:** handle the substantial variations in part configurations

Table 1.1: Flexible Manufacturing System and its Subsystems:

Physical Subsystem	**Workstations :** consists of NC machines, HMC/ VMCs, machine-tools, inspection equipment's etc.	**Storage-retrieval systems:** acts as a buffer during WIP (work-in-processes) and holds devices	**Material handling systems:** consists of power vehicles, conveyers, automated guided vehicles (AGVs) etc.
Control subsystem	**Control hardware:** consists of mini and microcomputers, programmable logic controllers, communication networks, switching devices and others peripheral devices	**Control software:** a set of files and programs that are used to control the physical subsystems.	

Business and Industrial needs of today are not just limited to Ordinary Manufacturing using simple Lathe or Cutting-Bending operations. With the advent of terms like Aero-dynamicity and Material Cutting, manufacturers have become much more aware and conscious of the practices which they adopt. Of course, it is very difficult and not at all financially feasible to do all this through a Batch Production method which is extremely, inefficient as all equipment have to be stopped, re-configured, and its output needs to be tested before the next batch can be produced. For continuous manufacturing which is unhindered by external operations, we require a Flexible Manufacturing System which is all governed by a Centralized Computers and is on the lines of Computer Integrated Manufacturing, commonly abbreviated as CIM.

3. Flexibility versus Efficiency?

Contingency theory argues that organizations will be more effective if they are designed to fit the nature of their primary task. Specifically, organizations should adopt a mechanistic form if their task is simple and stable and their goal is efficiency, and they should adopt an organic form if their task is complex and changing and their goal is therefore flexibility (Burns and Stalker 1961). This trade off view has been echoed in other disciplines. Standard economic theory postulates a trade off between flexibility and average costs (e.g., Stigler 1939, Hart 1942). Operations management researchers have long argued that productivity and flexibility are innovation trade off against each other in manufacturing plant performance (Abernathy 1978; see reviews by Gerwin 1993, Sua´rezetal. 1996, Correˆa 1994). In support of a key corollary of the tradeoff postulate articulated in the organization theory literature, they argue that in general the optimal choice is at one end or the other of the spectrum, since a firm pursuing both goals simultaneously would have to mix organizational elements appropriate to each strategy and thus lose the benefit of the complementariness that typically obtain between the various elements of each type of organization. They would thus be "stuck in the middle" (Porter 1980).

4. Moving beyond the Trade-off?

Empirical evidence for the tradeoff postulate is, however, remarkably weak. Take, for example, product mix flexibility. Other researchers argue that while the trade off can be shifted, much of what we observe when firms make notable improvement in several dimensions at once represents catching up to best practice (Skinner 1996,Hayes and Pisano 1996, Clark 1996). We conclude from these views and theoretical debates that if there is a tradeoff between efficiency and flexibility among the average performers in an industry, at any point in time some firms are below and others above this tradeoff line. It is not difficult to see how firms might find themselves below this line; but what do firms need to do to position themselves above it? More intriguingly, how can exceptional firms shift beyond the tradeoff experienced by even their strongest rivals?

5. Toyota in the world

Being established in 1937, Toyota is world's leading automotive manufacturer with a market share of 43% in Japan. The Toyota vehicles are sold in 170 countries and locations worldwide. Total net revenue of Toyota in year 2013 is ¥ 22,064,192

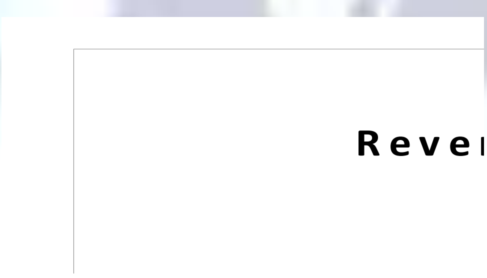


Figure 1.0: Other market consists of Central and South America, Oceania and Africa

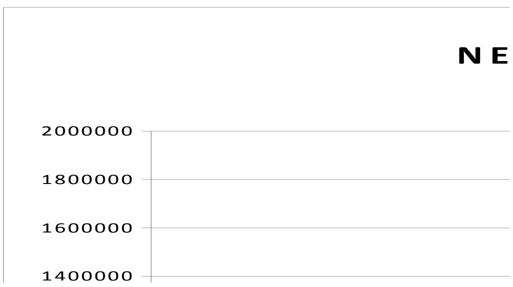
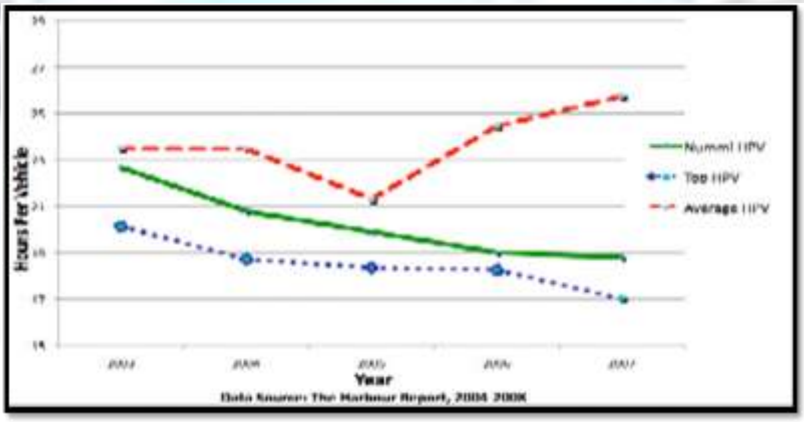


Figure 1.1: Toyota's net income increased by ¥73.8 billion, or 4.5%, to ¥1,717.8 billion during fiscal 2008 Compared with the prior year.

6. Research Context: Toyota's Case in context with Flexible Manufacturing

A case study of an organization that excels in both efficiency and flexibility dimensions can advance our understanding of these hypothesized mechanisms and impediments and of how the organizational context influences their relative effects. NUMMI (New United Motors Manufacturing Inc.) was one such organization previously owned by General Motors which underwent slow demise during 1970's before TOYOTA took charge of its processes and invested $100 million in 1984. In analyzing NUMMI's flexibility, we focus on its agility in major model changes from implementation of Flexible Manufacturing System to its resuming processes by overcoming challenges. System Beginning in the 1970s, the auto industry "dematured" (Abernathy et al. 1983). Whereas the bases of competition in the U.S. during the prior period were price and cosmetic styling, the new epoch brought ferocious competition from Japanese manufacturers who shifted consumer expectations concerning price and conformance-type quality while simultaneously differentiating products through design and technology. Products thus changed more rapidly and the changes were more substantial. Minor cosmetic model changes still occurred each year, but the frequency of major model changes—and the extent of product and process change associated with them— increased. Whereas the interval between major model changes in the U.S. Big Three auto companies had varied between four and eight years, competitive pressure led to a shift toward the lock-step four-year cycle adopted by Japanese companies and their U.S. subsidiaries. These major model changes represented a huge challenge to an auto assembly plant. The application of Flexible manufacturing System Anywhere between 60% and 90% of the 1500–2000 components that were assembled into a vehicle were redesigned, and as a result, most of both internal and supplier manufacturing processes were redesigned too. NUMMI operated at exceptional levels of productivity and quality. In 1993, for example, NUMMI took around 18 person-hours to assemble a vehicle, as compared to an average of 22 hours in a large sample of Big Three plants (Pil and MacDuffie 1996: note that their analysis controls for numerous factors that can distort interplant comparisons). The Figure 3 Indicates that NUMMI demonstrated "continuous improvement" in its productivity between 2003 and 2007 on its built-Corolla. Corolla ranked third out of eight North American plants in its class with 18.75 HPV, slightly behind the 17 HPV of the first place factory.

Figure 3- NUMMI productivity (hours per vehicle graph) Ranking compared to other North American sub compact Assembly Plants. (A declining line indicates improving productivity.)[10]



At the same time, NUMMI was significantly more flexible than its Big Three counterparts. Whereas Ford, Chrysler, and GM model changes in 1994 involved plant closures of 60, 75, and 87 working days respectively, NUMMI was closed for only five days for comparably complex major model changeovers in 1993 and 1995 during the Lean Manufacturing System as a Business Process Redesign Strategy. Whereas the typical Big Three plant often took six months to resume normal production rates after a major model change, NUMMI took less than four months for the 1993 changeover and less than three months for the 1995 changeover. Moreover, quality at Big Three plants typically degraded considerably at resumption of operations during the 1987–1995 period, J. D. Power Initial Quality data shows that the average number of problems per 100 domestic model vehicles went from 135 in the year prior to model change to 144 problems in the year of the model change. And the typical Big Three plant only returned to its normal quality level after a period lasting anywhere from three months to over a year. Since most model changes occur in August, the annual J. D. Power and Associates scores are thus very sensitive to quality during the ramp up of new models.)

6.1 Shifting the Trade off: Key Findings

In accordance with the canons of inductive research, we present our results first, in this section, then present the supporting evidence in the following three sections. Our results fall under two broad headings: mechanisms and context.

6.1.1 Trade off-Shifting Mechanisms

First, NUMMI had many more meta routines than traditional Big Three plants to guide the performance and increase the efficiency of non-routine activities. Second, NUMMI derived considerable trade off shifting benefit from the enrichment of routine production tasks. Continuous improvement was defined as a key additional responsibility of production workers, indeed of all NUMMI personnel. Workers were encouraged to pull the “andon cord” to signal problems in their work and stop the line if necessary. NUMMI’s managers put a premium on mindfulness in the conduct of routine activities. The Pilot Team was a novel specialized unit, working alongside an engineering changeover team, responsible for designing the work process for the new model and for training workers for their new assignments. Meta routines also indirectly encouraged greater flexibility by facilitating the identification of anomalies whose resolution represented

Opportunities to further increase flexibility. The direct effect of the remaining three mechanisms was to increase the organization’s innovation capabilities and thereby its flexibility. They also indirectly encouraged greater efficiency when these innovation capabilities were directed at improving ongoing operations.

Contextual Factors

Our analysis of the NUMMI case highlighted two key features of this context: training and trust. Training was critical. If people lack the knowledge, skills, and abilities required for the effective implementation of the four basic mechanisms, the tradeoff cannot be shifted. NUMMI invested far more than Big Three plants in worker training. Trust proved to be a second critical contextual factor. First, NUMMI’s culture placed a high premium on consistency, on “walking the talk.” The credibility of this commitment was but buttressed by strong union voice. Second, in many organizations managers and subordinates distrust each other’s competence to fulfill their commitments (the Sako (1992) and Mishra (1996) competence trust, the Mayer et al. (1995) ability trust. NUMMI’s extensive training investments assured high levels of worker competence. NUMMI’s extensive technical support for suppliers motivated high levels of trust in supplier competence.

Third, all four mechanisms can easily be undermined by lack of trust in goal congruence (Sako’s (1992) goodwill trust, Mishra’s (1996) openness and concern). At NUMMI, “teamwork” was a core value expressed not only in the organization of workers into small production teams, but also in the ethos governing relations between departments and vertical layers, as well as in labor and supplier relations. All three kinds of trust appeared in both interpersonal and system forms. Alongside the three types of interpersonal trust, NUMMI performance was also predicated on stakeholders’ trust in the consistency, competence, and congruence of NUMMI’s management system, its supplier relations systems, and its labor relations system. By making its own success a hostage to employees’ goodwill, NUMMI management committed itself to not taking advantage of opportunities to hurt the workforce.

6.2 Toyota’s Production System

TOYOTA’s production control system has been established based on many years of continuous improvements, with the objective of "making the vehicles ordered by customers in the quickest and most efficient way, in order to deliver the vehicles as quickly as possible.". The Toyota Production System (TPS) structured the work process at NUMMI under four main

TPS principles:

- Just-in-time production,
- The team concept,
- The jidoka concept of quality focus and
- Work standard, Kaizen

The Just-in-time process produces only what is needed by the succeeding process in continuous flow. By eliminating buffers at NUMMI, the problems and bottlenecks quickly became apparent and identifiable. Workers at NUMMI were divided into teams of four to six, each of which had a union member as Team Leader. Jobs were very modestly enlarged: work cycles remained at the industry norm of about 60 seconds, but Team Members often rotated jobs within their team. This not only relieved boredom and ergonomic strains, but gave workers a broader understanding of the production system. Jobs were also modestly enriched, by giving production workers some responsibility for quality, minor maintenance tasks, and line-side housekeeping. Team Leaders functioned primarily as lead hands, with modest administrative responsibilities but no managerial authority.

The Jidoka process of TPS works on the principle that when problem occurs, the equipment stops immediately for the prevention of defective products being produced. To avoid waste and facilitate to identify the root cause, NUMMI aimed to catch defective part immediately by conceptualizing Jidoka. The fourth major concept Kaizen, aims at continuous improvement was NUMMI’s approach to scientific management where Team members and Team Leaders identify the optimal procedure for each job. NUMMI had a different mechanism as compared to other Big three counterparts of capturing ideas from workers. About 1800 suggestions were given by the workers and team members during the suggestion program in 1992. Suggestions that passed muster became the new prescription, but only until the cycle was renewed by the next suggestion.

6.1.3 Toyota's Management System

NUMMI's implementation of the Toyota Production System was buttressed by management policies that encouraged worker commitment and skill formation. One important set of commitment-enhancing policies involved relations with the union. NUMMI and the UAW used a joint problem-solving approach on many issues that were closely-guarded management prerogatives at GM-Fremont. In addition, the collective bargaining agreement promised a measure of job security. The company's successful efforts to avoid layoffs during a mid-1980s downturn greatly enhanced employees' confidence in the company's no-layoff commitment. Kaizen activity was encouraged by a gain sharing system rewarding all workers for improvements in plant-wide quality and efficiency: since its introduction in 1990, it paid out $645 in 1992, $733 in 1993, $1,285 in 1994, $1,130 in 1995, and $1,316 in 1996. NUMMI also pursued many avenues for skill formation

6.1.4 NUMMI's Model Change Process

At NUMMI, unlike traditional American System, the early interactions between design, engineering, and manufacturing personnel facilitated the timely discovery of many misfits. It also allowed for more creativity in improving fit quality, through aggressive efforts in value engineering. The goal of this collaboration—indeed, the "secret" to NUMMI's model changeover agility according to a senior Toyota manager—was rigorous certification prior to the resumption of operations that "man [read: workers], machines, materials, and methods" were capable of doing their intended jobs. Not only did this certification dramatically reduce the number of changes required after start of production, but certification also created a set of standards that reduced the need for (costly) mutual adaptation in specifying any later changes that did need to be made. NUMMI thus derived considerable benefit by "front-loading" mutual adaptation that is, shifting it to earlier phases than the Big Three. The Big Three's traditional management model assumed that the changeover task could be managed sequentially, relying on standards, plans, and schedules to assure interdepartmental coordination. NUMMI aimed at a higher degree of joint product/process optimization, and they therefore interpreted the changeover task as embodying more uncertainty than the Big Three did.

6.1.4.1 Pilot Production

Five months prior to the start of production, NUMMI workers built the first set of 25 pilot vehicles. This first pilot build focused on engineering issues. It was therefore conducted off-line in the pilot area, and it relied primarily on parts that were custom-built by suppliers. The benefits of a pilot run on the regular production line with regular production workers were immense: far more problems could be identified than was possible in an off-line pilot build. NUMMI's management of its pilots offers three salient contrasts with traditional Big Three practice (see also Clark et al. 1992). First, Big Three plants typically did not do on-line pilots in already-functioning plants; they waited until after the old line had shut down and the new equipment had been put into place.

This considerably delayed identifying and solving problems. Second, U.S. firms were traditionally guided by cost concerns and were under little pressure to accelerate changeovers; as a result, they laid off most of their production workers during the protracted plant shutdown, recalling them progressively as production accelerated, and training them only as they came back into the plant. Third, these returning workers were trained by the small group of core workers who conducted the first pilot builds, whereas at NUMMI, Group Leaders and Team Leaders had the primary responsibility for training.

6.1.4.2 The Acceleration Period

At the cost of some overtime to accommodate training and pilot builds, NUMMI produced a full schedule of the old model vehicle right up to the week before production of the new model began. On August 7, 1992, NUMMI stopped production for one week to prepare for the changeover. During this week, the Pilot Team worked with managers, engineers, and maintenance workers to set up the new line. Production workers were required— as they had been warned a year in advance—to use a week of their vacation time. When operations resumed on August 14, the Team Members returned to new jobs.By contrast, the traditional Big Three accelerations were significantly handicapped by the gaps in knowledge and conflicts of interests that marked the relationship between workers on the one hand and industrial engineers and managers on the other.

6.1.4.3 Problems in the Acceleration

The new line took only 77 days to accelerate to full production. This was far faster than typically found in Big Three plants, but not as fast as NUMMI's original plan of 60 days. The acceleration had to surmount three sets of unanticipated problems. First, some of the new technology introduced with this model change-notably, a doors-off conveyor and an instrument panel sub-assembly line-broke down more often than expected. Second, some parts did not arrive on time. NUMMI had changed some of its supply logistics, consolidating some deliveries in Chicago and taking more frequent deliveries; errors in planning and executing these changes led to delivery delays. Third, numerous part-fitting and "workability" problems appeared, partly because of weaknesses in some US suppliers.

Conclusion

Our analysis of NUMMI has revealed it to be an organization that has repeatedly shifted the efficiency/flexibility tradeoff. It had an exceptional capability for both first-order and second-order learning. Four mechanisms made this possible. Meta routines made non routine tasks more routine, with the direct effect of increasing efficiency for given levels of flexibility and the indirect effect of creating opportunities to increase flexibility. The other mechanisms—job enrichment, role switching between improvement tasks and production tasks, and partitioning NUMMI's structure into a changeover team and an operating core—had the converse effects: directly, they increased the organization's capacity for flexibility at a given level of efficiency, and indirectly they created capabilities that served to improve efficiency. Organization theory suggests important potential impediments to each of these mechanisms, but NUMMI overcame them because its bureaucratic core, its non routine components, and its supplier relations were all managed in a high-trust mode. Routines and meta routines were thus embraced rather than resisted. Organic and bureaucratic structures and roles were integrated rather than opposed. Suppliers were mobilized rather than fended off.

Leadership would appear to be the key precondition for such persistence. Without committed leadership, NUMMI could not have made its huge investments in training: investments that paid off only in the longer term and often only in indirect ways. As a high-trust, unionized firm, the leadership function at NUMMI was somewhat more distributed, and the union shared some of its burdens. And to the extent that NUMMI's ambidexterity relied on high trust relations with suppliers, leadership in the supplier firms too played a key role. Future research should also extend our temporal horizon. Our comparison of traditional Big Three practices with NUMMI practices masks an important evolution over the longer time period. Future research could usefully focus on delineating the sequence of organizational innovations that have progressively shifted the tradeoff frontier. Some of these innovations lie in the domain of organizational structures and processes, and some in technology; long-term shifts in the broader institutional context may also have played a facilitating role. A better understanding of this history might give us more insight into the prospects for the future evolution of trade off-shifting organizations.

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