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F W Taylor Memorial Lecture

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Background of
F W Taylor Memorial Lecture

Inventor and engineer, Frederick Winslow Taylor was born on March 20, 1856 at Philadelphia, the USA.

Educated at preparatory schools at Pennsylvania and New Hampshire, Taylor entered apprenticeship in the trades of pattern maker and machinist in Philadelphia in 1875. In 1878, he was employed by the Midvale Steel Company in their machine shop. In 1881, he introduced his method of increasing the efficiency of production by close observation of individual workers, identifying and eliminating wasted time and redundant motion. He earned a degree in 1883 from the Stevens Institute of Technology, and in 1884, he was elevated to the position of Chief Engineer at Midvale. In 1890, he became the General Manager of the Manufacturing Investment Company. He subsequently became consultant in management in a number of organizations. Having dedicated about forty years in the improvement of production techniques and productivity, Taylor earned the distinction of being the father of modern scientific management. He expired on March 21, 1915.

In memory of his dedicated service, The Institution of Engineers (India) instituted an Annual Memorial Lecture in his name during the National Convention of Production Engineers.

F W Taylor Memorial Lecture

presented during **National Conventions** of **Production Engineers**

Innovation & Knowledge Management — Creating Globally Competitive Manufacturing in India

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Let me at the outset express my personal gratitude to the President and Honorary Secretary of M.P. Chapter of Institution of Engineers (India) for inviting me to deliver the coveted FW Taylor Memorial Lecture at this National Convention of Production Engineers. Ladies and gentlemen, I am conscious of the honour bestowed on me and also the prestige attached to the name of FW Taylor, the founding father of modern Management. Taylor, as you all know, was an engineer working in a manufacturing industry who has very keenly observed the work activity being carried out by his fellow engineers and fellow workers around him in the production systems. Those were the days or specialized manpower carrying out the work activity and a large number of co-workers were supportive of the main activity of production. The interrelationship between the various elements of the manufacturing chain, their direct and indirect influences on worker's productivity were least understood. The main task of the management was to meet the targets of production. Taylor realized that a lot can be achieved in terms of efficiency in production, in respect of high productivity and smooth functioning of the organization, if the whole system could be tuned to work on a set of principles. Taylor evolved the first ever set of principles of management which were later designated as Taylor's 14 Principles of Management. These included division of labour, line or authority, unity of commands and now of authority etc. The foundation of modern scientific management was thus laid by Taylor who even to date is regarded as the father of modern management. I therefore feel highly elevated to have been invited to deliver the memorial lecture in the name or the brightest engineering genius, FW Taylor, the founding father of modern management. In fad the development or modern management during the last 100 years is structured around the Taylor's principles of management.

Like any other system and a code for smooth and efficient functioning of human endeavor the management also has undergone continuous evolution. In fact, it has graduated from being an art which it was upto about 1960’s to being a science in the decades or 70's to 80's. However with the rapid growth or communication technologies, later integrated into computer applications, the management today is more or engineering and technology than merely being a scientific application or the basic principles of management. The rapid growth or knowledge and product innovation in today’s IT driven industrial and economic environment is exerting a compelling influence on the codes and practices of management. Managerial procedures, organizational structures, system dynamics and the practices of production and quality management are therefore undergoing as rapid a change as the pace of change of knowledge and technologies. Managing knowledge, managing innovations and managing frequent technology changes arc the major challenges to be addressed to by the management of modern enterprises and industry houses. I have therefore chosen to devote today’s FW Taylor memorial lecture to the managerial imperatives or Innovation and Knowledge Management.

INDIAN MANUFACTURING INDUSTRY IN THE GLOBALISED ECONOMY:

Manufacturing in India's surged and has undergone a phase of rapid growth during the first few decades after independence in 1947. The protection and patronage it enjoyed from the socialistic outlook or the Government and the vast Indian market provided a fertile ground for the growth or Indian manufacturing industry. We find that the key and heavy engineering industries in India such as BHEL, Bhilai Steel Plant, Heavy Engineering Corporation, HMT and Bharat Earthmovers were all setup by the Government as public undertakings. These industries flourished in the protected economy era. The growth of small-scale industries, SSIs, in the country in manufacturing as well as in consumer electronics has been highly impressive. An average annual growth or 15-20% was achieved during 80's and up to mid 90's. Today or course the scene is quite different. Indian manufacturing is rapidly declining. The SSIs are under heavy pressure from the MNCs and industries abroad. They are intact facing a severe threat or extinction. I am hearing or closure or industries, laying all of employees, voluntary retirement schemes arid golden handshakes in Indian industries these days. In fact I have witnessed such key words ill newspapers ill U.K. during late seventies and eighties while I was there. There must be similarities. I presume, in scenario prevailing ill Indian manufacturing industries today and that of U.K. industries in the late 70's and 80's. I find the following similarities:

- Low productivity in production.

- Luck of investment in new technologies.
- Loss or focus of product innovation.
- Poor quality production and large avoidable expenditure.

British industries in those days being old were facing technology obsolescence as against their counterparts in Japan, in Europe and in U.S.A. In India the neglect of constant upgradation of technology levels in the industry has created a situation of technology obsolescence in the industries. The British industry being conservative in its product outlook was unable to match the rapid pace or product innovation and process modernization as much as its competitors abroad. Compared to this in India there has been a total dependence on foreign collaborations for import of technology, knowledge and product designs. The lack of environment for product innovation and urge for indigenous development of technology and expertise have pushed the Indian industries to wall when the field was wide open to multinationals from abroad and the flood gates were wide opened for import of goods manufactured outside India. The outcome is quite obvious. You have seen the high and mighty BHEL, SAIL, HEC and of course all sectors of Indian industries facing the toughest time ever. Let us look at the reasons from close quarters.

I. LOW PRODUCTIVITY IN PRODUCTION:

Workers productivity in India is all to well known to be no more than around 20 times less than that of that of Japan and other highly productive systems in the developed countries. It is not technology that affects worker's productivity. I must emphasize there are a whole lot of factors including the work culture, education, training and retraining of the workforce, interest and enthusiasm of one and all in success of the organization, the role of management in inspiring every one right from the lowest in the manufacturing chain to the top most in the hierarchy to tune to productivity consciousness, rewards and incentives for coining good and useful ideas, workers participation in management and of course inductment of new technologies and system up gradation, all go in a long way to create productive organizations. The urge to produce anything of whatever quality and dump it in the home market intact created conditions conducive to the growth of highly inefficient system of production in India and have constrained Indian industries to achieve high workers productivity. You may however ask as to why during 10 years of a globalised economy in India we could not improve workers productivity and create a globally competitive Indian manufacturing sector?

LACK OF FOCUS ON PRODUCT INNOVATION:

In the modern science and technology driven economy era, the industries roar with success at home as well as in the international market on the strength of the innovations in product design. Product innovation has become one of the most powerful instrument of creating global competitive edge in today's highly competitive market driven economy. When we look at our industries in India we find the lukewarm response to product innovation and continuous improvement of quality and productivity has infact provided a highly uneven play field for our industries when the globalized economy era began some 10 years ago in July 1991. The globalization and liberalization opened immense opportunities for Indian industries to respond to the challenges of quality and product innovation. With a strong base of S&T manpower and basic infrastructure for technological competence, it was indeed a golden opportunity for the Indian industries to emerge out as leading players in the manufacturing sector. But the inertia of the protected economy has not been shaken as fast as was stipulated. Indian industry did not take its HR competence seriously, and continued to look outside India to outsource its product design and technology requirements. The net result is quite obvious the Indian engineers continue to be more and more in demand in the advanced countries who took the opportunities of globalization seriously and made strong inroads in the developing countries. Intact the Indian industry lost very heavily in the manufacturing sector to the multinationals from abroad. You may ask as to how a industry ridden with financial crisis can focus on product innovation when it has not enough strength to even continue? Product innovation is a process by which good ideas from both academic, industry and society quarters are channelised to yield new and improved designs, are translated into products, which create a market wave. However, in India because of a very low or little interaction between the industries and the institutions, the pooling of the minds and synthesis of ideas has not become a reality. 10 years of globalization have failed to create a real impact on the industries at home to realize the value and worth of industry-institute linkages. What is required is to understand that the industries should go beyond recruitment of the graduates and postgraduates and establish synergetic partnership with the institutions so that the rich intellectual wealth of our nation is translated into the strength of our industries. It is rather disappointing that industries in India during the last 10 years of the globalised economy have only understood the value of alliances and collaboration with the high and mighty abroad and neglected the core-strength which could have been created by such alliances with leading Indian institutions and R&D houses.

In today's IT environment the speed and pace of product innovation and management of technology change make it imperative that the dynamics of Innovation and Knowledge Management be better understood Quick and favourable response to good ideas, rewarding the valuable ideas, pursuing good ideas with speed through innovation management teams and through rapid prototyping taking the most valuable ideas to the market in the form of improved and innovated products is what is required. Vast global international market is reachable to India as much as to China and others purring the Indian Industry could understand the value of productivity, innovation and knowledge management.

The industries in India especially in the manufacturing sector arc poised for resurgence if they lake the challenge of managing innovations and managing knowledge seriously. We have all the ingredients of success in this country including internationally acknowledged human resource competence, basic infrastructure for inhouse technology development and a strong base fur S&T education and research, what we lack, of course, is the strategy to harness rich talent, which we possess. We also do not have efficient mechanisms for converting knowledge into prosperity by taking the ideas to the product innovation levels. I am sure the industry understands the imperative of productivity in production, quality at all levels and the dynamics of global competition, which compels us to think of total quality and cost management as the hallmark of our initiatives and professional practices, The industries undoubtedly need the support of the government as far as the industrial policy initiatives are concerned. The industrial policy of the nation is to be targeted to create j Advantage India', which means supporting our industries to acquire capabilities of producing world class products and services, facilitating channels for international trades for marketing of Indian products abroad. The question is when China can do it why not India. India's vast population can be converted into a real human power by ensuring that opportunities fix employment and self-employment are created in abundance. This requires a careful planning of our industrial development in the changed globalised economy environment. Let the industry also understand that the days of protection are gone but certainly the industry cannot be allowed to reel under the global pressures of uncontrolled flow of imported goods and services currently being witnessed in the Indian market. Every nation has its first and foremost duty to protect the interest of its people and no policy on the earth can deprive India and its people an opportunity to use their capabilities for strengthening the basic fabric of economy of this country.

I have already made my views quite clear about the dire need for synergetic partnership between the industries and the institutions, between the industries and R&D organizations and between the industries and the technological universities. Let a new era of partnership for progress begin in this country where by the core competence of the faculty and students in the institutions is utilized by the industry for creating global competitive edge in respect of knowledge, know-how, technology and product innovation. Let the core competence and the expertise and vision available in the industries help the educational institutions and R&D houses in targeting their efforts for creating a strong and globally competitive industrial base in this country. Let there be a much greater cooperation between the industries and the institutions and let you from the industries and we from the institutions work together for a common cause that is to create world-class institutions and undoubtedly globally competitive industries in India.

Ladies and gentlemen, it is important for each one of us to realize the importance of our partnership and ensure that in this new information age we are not left behind in management or innovation and knowledge specially that we have registered our claim and have successfully demonstrated our capabilities in the Information Technology sector ill this country. What is required is to make the best use of our IT capabilities and our human resource competence in our industries and bounce back with roaring success in the market at home and abroad. Let me pray that this day comes much sooner than expected and let the Indian industry march on the path of resurgence from now onwards.

I felt highly elevated in sharing my views with you specially that you have invited me to deliver the coveted FW Taylor Memorial Lecture at the National Convention of Production Engineers organized by the Institution of Engineers (M.P. Chapter). I can assure you that we at the Rajiv Gandhi Proudyogiki Vishwavidyalaya, the State Technological University of Madhya Pradesh are firmly committed to work with our industry partners, to create Advantage India by our efforts. Let you support us to become a world class technological university and let we provide you all that is desired from the academia and the science and technology community to create world-class industries ill our country. I have great pleasure in extending my very best wishes for the success of the National Convention and I take this opportunity to thank the organizers for giving me this opportunity to be with you today and share my views.

Ladies and gentlemen, may I thank each one of you for your patient hearing.

Thank you.

IT in Manufacturing

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Abstract

Information Technology plays a strategic role in improving the productivity of an organization. In view of electronic linkages, it provides elimination of time delays and geographic linkages and hence enhances competitiveness in the liberalized global market. Particularly in situations of fluctuating demands, frequent design changes and low batch manufacture, IT is highly effective since it enables real time response. The paper includes findings of a study, carried out for Asian countries, illustrating varying degrees of utilization of its potential. Critical factors, for its effective usage, have been identified and subsequently some guidelines have been suggested. The concept of VEs is briefly discussed which are now progressively showing their importance in global situation, in view of agility, synergy, enlargeness and competitiveness these provide to member organizations.

Keywords: Manufacturing, IT, VE, CEo

1. Introduction

The objective of this presentation is to present an understanding of application of IT in manufacturing with a view to learn present status and thereby suggest as to what should be done to obtain competitive advantages in the global economy. All APO study [1] illustrates the key factors and obstacles in adopting IT strategy in economic development in Asian countries. To be competitive in market, effective management of cost and time is required, i.e., resources. With the dynamics of the market, this aspect is getting increasingly complex. To deal with this, industries have gone for sophisticated ERP solutions by adapting softwares like SAP, BAAN etc. [2]. A significant improvement in the design and manufacturing function in the manufacturing industry was reported due to computerization, i.e. CAD/CAM [3]. These development were inevitable in view of changed manufacturing environment of customer driven market [4][5][6] calling for frequent design changes in products, ever increasing demand for variety of products, better quality in terms of precision and shorter product lives. This was also compounded with varying batch sizes of small and medium content, sometimes even one off, and varying and shorter delivery periods often associated with monitory penalties sometimes resulting in loss of future business. The emphasis has been on progressive reduction in lead times and therefore use of CNCs alone was not sufficient. What is required is that the business function is also integrated with design and manufacturing functions i.e. Simultaneous engineering or Concurrent engineering, so that the entire information is dealt with a totality and in real time.

From the literature so far published, typically reported in [5][7], it is found that there has been highly appreciable advancement regarding use of IT in most areas. However, its application in manufacturing has not taken place to its fullest extent and wherever it has been applied, it appears to be in fragments or partial integrated.

Meeting the dynamic demands of market requires extensive communication between many people within the company and between companies [8]. Lack of communication leads to poor processes, e.g., a survey [9] reported that 'poor communication' and 'problems discovered too late resulting in panic and leading to quick fix solutions' were two most significant barriers. In the most developed countries in the world, integrated information systems have been in use, which encompass the vendors and customers too, besides various levels/sections in the manufacturing organization itself To cater for the needs of customers all over the world, a number of organizations, small and medium, collaborate and cooperate to provide for lean manufacturing. This has also shown importance of amalgamating the use of SCM and ERP solutions [2] through web based solutions [10].

2. Objective of the study

Understanding the importance of "Information" and its "Integration" for the manufacturing industry, a study was carried out in some Asian countries. The objective of the study[l] was to know the present status of usage of IT in manufacturing applications, to suggest critical success factors, how to implement IT, problems to be overcome in its implementation, and what supportive action is necessary. Various national experts carried out detailed studies in their respective countries and based on the same the author, as chief expert of the survey team, prepared the integrated summary.

3. Overview

Asia is an extensive continent wherein the development of the countries widely varies. Same is the case with the levels of literacy and the levels of infrastructure. The most developed country was found to be having maximum IT applications. Thus it could be easily summarized that for faster progress, the developing countries should rapidly go for higher IT usage. Even in the case of the highly developed countries, resistance to change was found to be a major impeding factor. This was, however, avoided by excessively high level of commitment of management. Education and frequent training was an importance factor in faster application of IT in organization. Everywhere it was felt that lack of standardization in hardware and software was a serious hindrance in progress. Many a times, work was carried out initial stages had to be scrapped in view of newer developments in software and hardware since interfacing posed major hurdles [1].

IT development is extensively labor oriented. In context to our country, this has offered manifold advantages in view of our large scientific manpower. Also that IT does not require too expensive infrastructure and that Internet enables global communication. This gives a major opportunity to developing countries provided their manpower is properly educated and trained. Since in our country, English is the medium of instruction, it has enabled better opportunities to us compared to many of our neighboring countries.

There has been large turnover of IT manpower within the country and to other countries. This could be due to insufficient capacity and specialties of the employers. Further, conventional education background and requirement of IT opportunities do not match. This aspect needs serious introspection and thereby the education and training programs need to be properly planned over a period of time.

The government has a major role to play in term of working out a policy on IT and providing infrastructurestable/ continuous power supply, communication network and proper planning of education system. There should be complete commitment on part of management of all major companies towards IT, and a vigorous effort on part of developers to standardize hardware/software. The professional societies should pressurize the government and industries to achieve these objectives. International bodies should encourage interaction, in form of training and collaboration, for advancement of IT and its application.

4. Concurrent Engineering

It is well known in industry that problems creep in production due to lack of coordination between design and manufacturing. Even though both of these activities have been computerized, but their existence in water tight compartments does not lead to overall increase in productivity. Onset of DFM, DFA and CAD/CAM were the steps to bring about overall coordination. Pure CAD approach is not amenable to manufacture, since the former stresses on the geometry aspects like points, lines, curves etc. To give that a manufacturing meaning, we need to define manufacturing features like holes, grooves, taper, slot etc. Information and communication technologies have changed equilibrium of costs between performing activities within the organization and co-operating with other to obtain needed services. Many product development concerns have found that this allows greater co-operation between firms in the design of new product [11]. Firms have also found that product development effort benefit from early involvement of many functions besides product design, i.e., manufacturing and marketing. This approach to design is well known as Simultaneous or Concurrent engineering [12].

In concurrent design and manufacturing, one of the most difficult task is creating link between computer aided design and computer aided process planning. It needs a proper interface and feature recognition or extraction is the key to achieve this objective. Geometric & non-geometric information associated with features is essential for process planning [13].

5.Virtual Enterprise

Organizational aspects have received much attention compared to that for re-engineering related to product development [9]. Situated in the environment of globalized markets and increasing customized orientation, modern enterprises are impelled to seek new paradigms, such as CE, lean production, agile manufacturing and virtual enterprise (YE). The latter are temporary organization of companies that come together to save costs and skills to address business opportunities that they could not undertake individually. Firms may cooperate with suppliers and engineering partners for several reasons. They may find it quicker or more cost effective to bring in a needed skill rather than develop the capabilities in house, or they seek partners in order to respond quickly to the change in needs of the customers [5]. These partnerships developed for a period, short or medium, are like virtual enterprises [14].

By now, a large number of projects have been launched for YEs. Most of them intend to develop information infrastructures and support platforms focussed on extending and integrating various standards and enabling technologies. One such is STEP (Standard for Exchange of product model data) [15].

The YEs offer agility, complementation, achieving dimensions and competitiveness [10]. Planning, design and operational requirements of YEs need for logistics flows through networking of distributed SMEs, which cannot be handled by commonly, used SCM packages. The solutions need to be developed not to substitute but to be integrated into SCM and with, in the broader sense, ERP solutions [10].

Web based industrial information systems are widely accepted and recognized as one of the most challenging for the development and implementation of modem industrial systems [16]. The challenge stems from the fact that Internet and in particular web is a completely different computing environment compared to conventional computer practice [7]. The most crucial issues in modem industrial information systems are flexibility, adaptability and maintainability. For this, component based approach-implementing business processes are needed. When change takes place, corresponding software component is adapted appropriately while existing could be used for different enterprises to reduce development time. A case study on inventory subsystem of an industrial information system has been reported by [7], applicable for a company having several branches located at different areas controlled by the central office.

6. Critical Success Factors

While large and medium scale industries are well advanced in IT applications, but the small-scale industries, which form the majority of the manufacturing sector, are still at the low end. Neither they have the experience not expertise in IT related areas. The findings of the study [1] are as follows:

- Entire company cannot adopt IT. Valuable experience can be gained by applying it to only a part of the process.

- Identify the critical information point. It could be a core section that affects other sections. This should be the start point.

- Identify the IT application needed, and thereby the hardware architecture and corresponding software.

- Expand application to other sections. For this, the processes should be systematized before expansion of application. May be, some changes will be required.

- Rather than putting IT to use in advanced technology, advances in IT need to be studied and explored for use.

- It is expensive to computerize difficult decisions or deal with exceptions. Human being is flexible but is not fast and accurate in repeated activity. Appropriate man-machine combination need to be chosen for the concerned industry.

- Motivation and persuasion is vital. There is always a resistance to change work and environment, even when one understands the advantages. For this the processes should be systematized so that these are easily understood.

- Do not talk of retrenchment. Instead, the objective is shortening lead-time, quality improvement, cost reduction and improvement in productivity. Expanding business should be the motive.

- The processes would necessarily need restructuring. Flatter organization with delegation of authority at lower levels should be designed.

- Company cannot afford to have its own specialists. External consultants and off the shelf software should be used effectively. However, the consultants must be clearly briefed on company's business and close cooperation offered at all stages so that software are properly customized.

- Management commitment is of prime importance. The CEO should work on the system, interact with people and be eager to learn and provide full support to people associated.

7. Conclusion

In many Asian countries, and even in many industries in the developed countries, IT applications have yet to come to its required potential. It has succeeded where the management has shown eagerness and will to adopt it. Public organizations and governments can play a big role by providing means for necessary education, training, infrastructure and monetary support. Standardization of hardware and software is vital for the success in IT implementation.

While the advanced countries have gone through a long period of IT development, the same results need to happen here in a much shorter time in order to be competitive. This calls for strong initiative by the government. Obsolescence should be understood and countered in a real way. Easy availability of investments in infrastructure and ever growing need for qualified manpower would be a necessity. Training and education in applications of IT should be expanded, regulated and updated frequently to meet rising requirements, continued quality improvements and quality assurance.

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21 Agile Competition: Evolution of Scientific Management

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Great Contributors:

Elihu Root (1845-1937)

"the first conscious and systematic application of management principles:" Peter Drucker

Henry Fayol — A french mining engineer (1841- 1945)

The universality of management.

Fourteen principles of management.

Frederick Winslow Taylor (1856-1915)

While Fayol wrestled with the broader theoretical question of the nature of management, Taylor was a man of devotedly practical intent, a problem solver. Taylor was a veritable Renaissance man. The breadth of his insights and interests is astonishing.

Taylor was an inventor, revolutionized metal cutting and enabled the development of mass production techniques & invented the power hammer.

Taylor then designed his own tennis racket, which resembled a spoon. His patent pageant also included a lawn tennis net (Patent No. 40 I,082 issued April 9, 1889)

Then Taylor turned his mind to golf. Like many other players through the ages, he encountered problems with his putting. There were no golf gurus to consult so Taylor P attempted to sort out the problem through his own inventiveness. The result was a Yshaped putter (Patent No. 792, 631, June 20, 1905) - perhaps the first attempt by anyone to beat the "yips". There is no evidence that this improved his game.

He had a passion for order and efficiency - typically, as school he revelled in the neatness of Dewey's classification and subject index for libraries.

Taylor was incredibly persistent. When in 1906, he presented his paper "On the art of cutting metals" to the American Society of Mechanical Engineers it was the result of 26 years of experimentation, including cutting over 800,000 pounds of 'steel and iron into chirps with experimental tools.

Records were kept of some 30,000 to 50,000 experiments costing the then enormous sum of between $ 150,000 and $200,000.

1997 Fortune magazine article noted" Taylor's influence is omnipresent; it's his ideas that determine how many burgers McDonald's expects its flippers to flip or how many callers the phone company expects its operators to assist".

Taylor's significant contributions are:

1. Measuring work.
2. Principles of work justice.
3. Cost reductions.
4. Analytical vigour of the work place.
5. Rationalist driver towards efficiency, effectiveness and productivity.
6. Establish the fundamental principles towards remanufacturing what we turn today is the agile competition or zero time manufacturing.

Five Zero Time disciplines:

- Instant Value Alignment
- Instant Learning

- Instant Adaptation
- Instant Execution
- Instant Involvement

Definition of Agility

The quality of being agile; the power of moving the limbs quickly and easily; nimbleness; activity; quickness of motion; as, strength and agility of body. Agility in business is often defined as the ability of a firm to sense and respond to business opportunities in order to stay innovative and competitive in a turbulent and quickly changing business environment. An agile firm (one that demonstrates agility) has the capabilities and processes to respond to unexpected environmental changes.

WHY DO WE NEED AGILITY?

- Market fragmentation
- Production to order in arbitrary lot sizes
- Information capacity to treat masses of customers as individuals
- Shrinking product life times
- Convergence of physical product and services
- Global production networks
- Simultaneous inter company cooperation and competition
- Distribution infrastructures for mass customization
- New product development
- Extensive customer service
- Building/ maintaining brand image
- Marketing innovation
- Influence over distribution channel
- Targeting unexplored segments
- Building/maintaining the firm's reputation
- Providing products with many features
- Premium product quality
- Operating efficiency/cost management
- Pricing below competitors
- Managing supply sources
- Process improvements/innovations
- Product cost reduction
- Serving special market segments
- Being first to enter into market
- Manufacturing/ Selling services
- Accurate market forecast
- Broad product range
- Maintaining high point of-sale inventory level etc

AGILE COMPETITION

A new form of commercial competition is spreading rapidly across the globe.

Agility is a generic concept extending over a spectrum of co-related developments that together define a comprehensive change in the prevailing system of competition.

At the level of the organization, agile competition is characterized by the ability to synthesize new, productive capabilities out of the available resources - the expertise of people and the physical resources - regardless of their physical location within a company or among groups of collaborating companies

At the level of Management, agile competition is characterized by a shift from the ritualistic philosophy to one of relativistic philosophy exemplified by leadership, motivation, empowerment and trust.

At the level of people, agile competition is characterized by the emergence of a knowledgeable, skilled, and innovative total workforce as the ultimate differentiator of successful companies from unsuccessful ones.

At the level of design, agile competition is characterized by a systemic methodology that integrates supplier relations production processes, business processes, customer relations and the products used and eventual disposal.

At the level of production, agile competition is characterized by the ability to manufacture goods and go deliver services to customer order in arbitrary lot sizes.

At the level of marketing, agile competition is characterized by customer-enriching, individualized combinations of products and services.

To succeed in such an environment, the company must learn to thrive on change and uncertainty not merely coping with them. Companies must re-position in the competitive spaces by adjusting structure, size, location, product and service lines, business processes, managerial practices, technology policies, human resource policies and marketing strategies.

AGILE MANUFACTURING

The concept of Agile Manufacturing is built around the synthesis of a number of enterprises that each have some core skills or competencies which they bring to a joint venturing operation, which is based on using each partners facilities and resources. For this reason, these joint venture enterprises are called virtual corporations, because they do not own significant capital resources of their awn. This helps to make them Agile, as they can be formed and changed very rapidly.

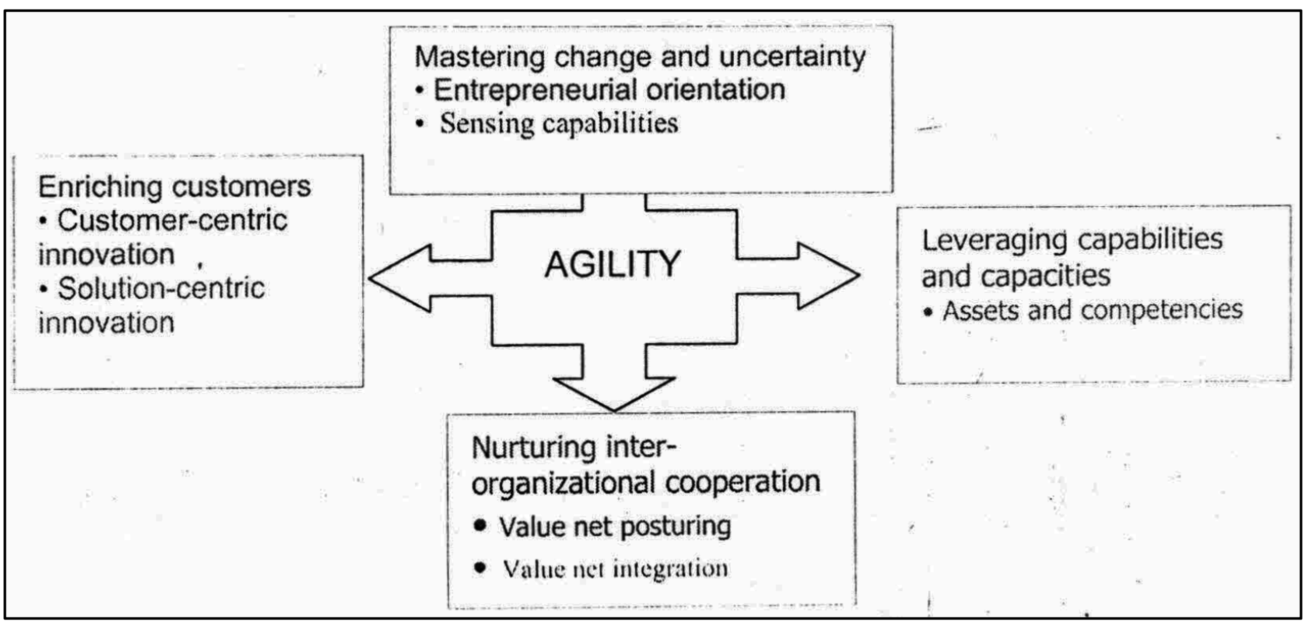
Agile Manufacturing is not like total quality management or business process reengineering. Agility is fundamentally about a different way of doing business, and put quite simply:

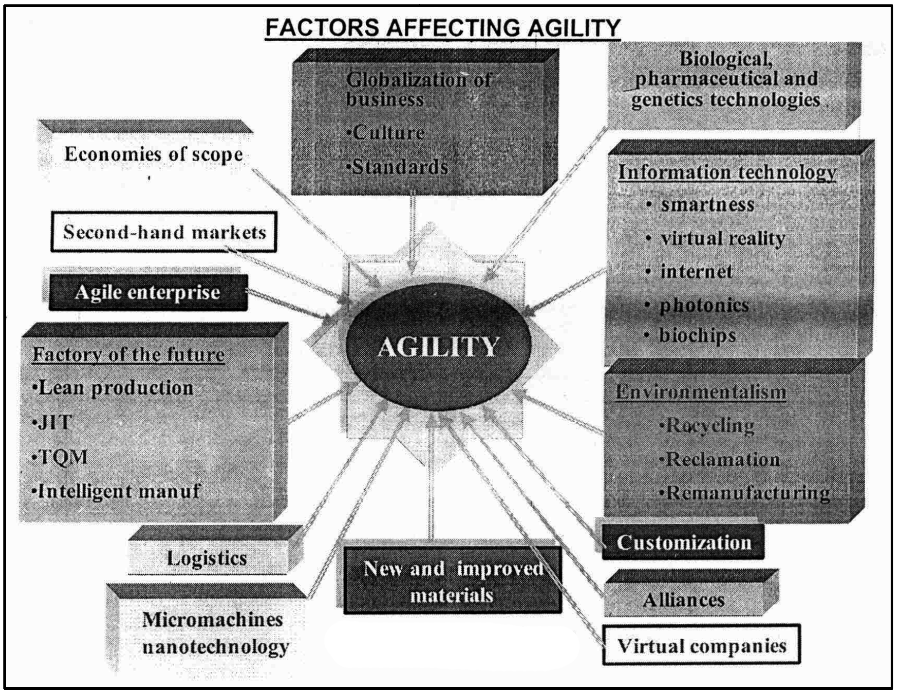
If you don't do business the Agile way, then ultimately you won't do any business at all!

FOUR DIMENSIONS OF AGILE COMPETITION

- Enriching the customers
- Cooperating to enhance competitiveness
- Organizing to master change and uncertainty
- Leveraging the impact of people and information

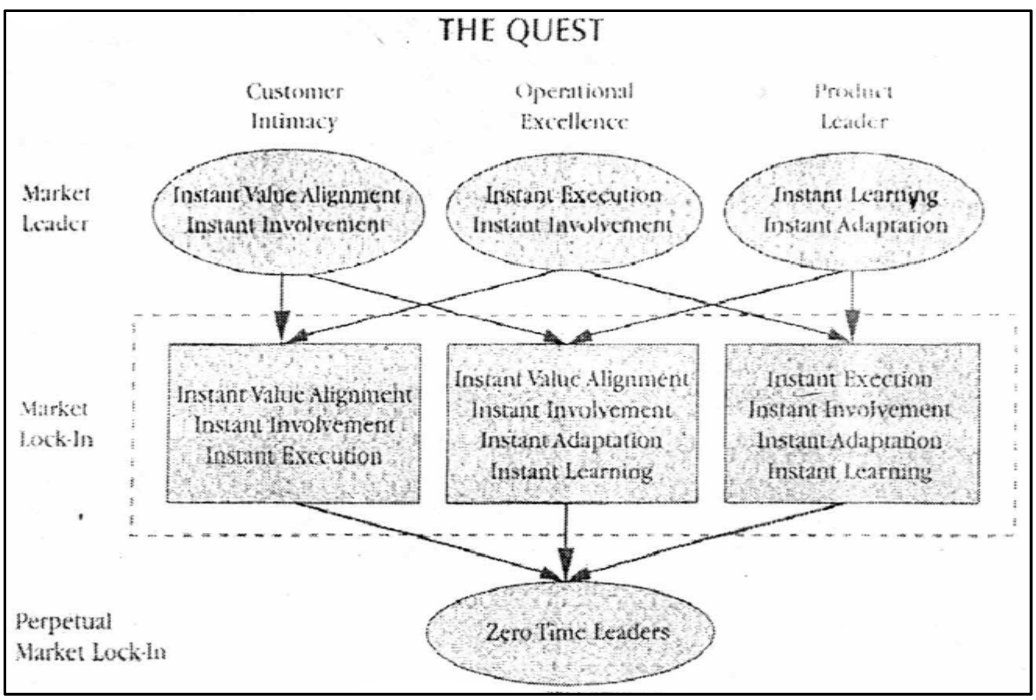
The Building Blocks of Strategic Agility

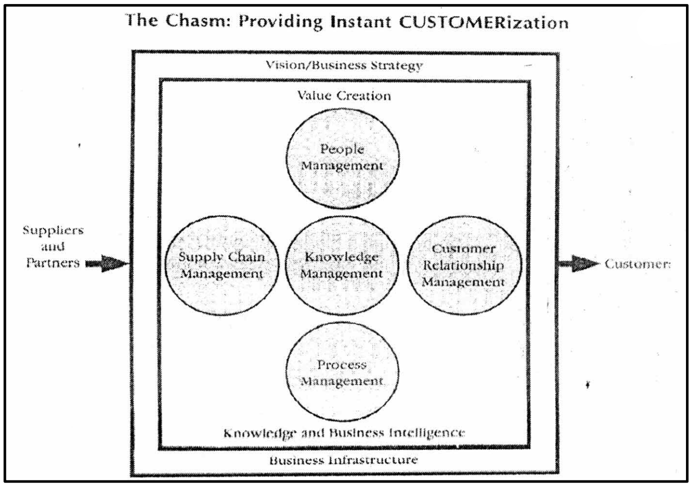




HOW DO WE PREPARE?

- global production network,
- enterprise integration in support of rapid product development for global market niches,
- virtual company organization,
- build to order, customer-configurable product with wide range of options, mass individualization,
- integration of information technology and design and manufacturing processes,
- remote cross-functional teaming, peer-level supplier and customer interactive relationships,
- leveraging impact of work force, management in leadership role, building motivation and trust in place of command and control, management as supporting operational work force.





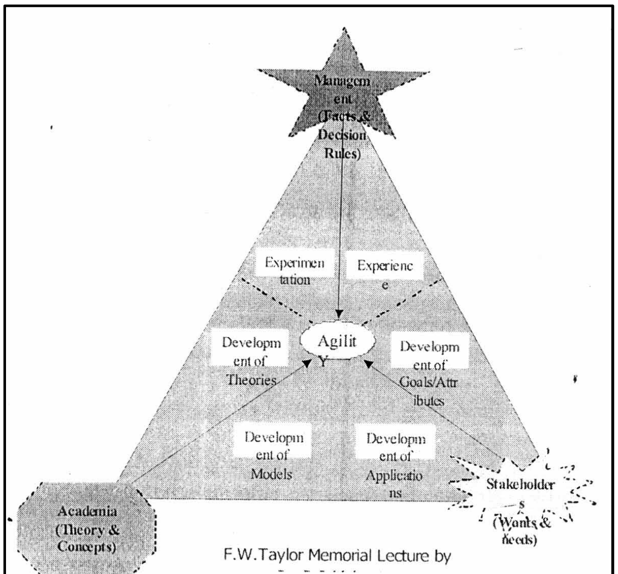


Fig. 13.1: Bounding the Agility

In the new competition, Manufacturing management moves in three Relational Spheres :

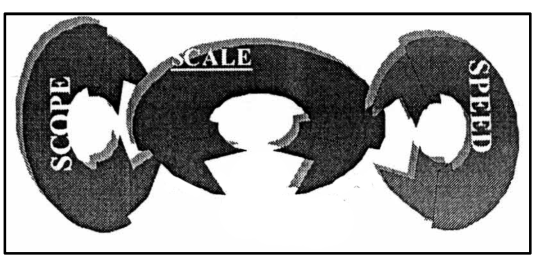
(1) customer relationships, driven by economies of scope,

(2) operations and infrastructure, governed by economies of scale,

(3) product innovation, governed by economies of speed.

Professional development Stems from the Interplay of these Three Relational Spheres.

All three must interact continuously and transform reflexively.



Re-engineering Indian Business Environment for Global Leadership: A Strategic Roadmap

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ABSTRACT

This paper attempts to develop a strategic intent for the Indian economy to be a global leader in next two to three decades by identifying Indian core competences, and its major constraints which are blocking it to reach its true potential. It identifies strengths and weaknesses of doing business in India and suggests a number of strategies which can overcome the hindrances and exploit the intrinsic strengths of India, its core competences and the demographic dividend by creating a powerful and enabling business environment. To facilitate India to become a global leader we need to focus on global employability of Indian Talent - a much wider form of IT than Information Technology, evolve right priorities in developmental process, empathize with customer and avoid myopic view of decisions.

Key words: Strategic Intent; Core Competence, Demographic Dividend; Employability, Education, Energy, Ethics

1, INTRODUCTION:

It is a privilege and honour to have been invited to deliver F.W. Taylor Memorial Lecture during the 25th National Convention of Production Engineers, I had the opportunity of visiting and' presenting a paper at the Stevens Institute of Technology, USA from where F.W. Taylor had graduated in the year 1883. Taylor, being a mechanical engineer proposed a rational, scientific approach towards improvement of efficiency on the shop floor operations, selection and training of the worker and financial compensation on rational basis. Some of his ideas are still valid. Though some of his ideas were not easily accepted even then but eventually he succeeded and won the title of "Father of Scientific Management". His passion to be rational in decision making and to improve efficiency and productivity is one main lesson that can be learnt if India is to be globally competitive. The theme of this memorial lecture is inspired by this Taylorian passion to; excel, so that India can leverage on its strengths, overcome those weaknesses which are blocking its development; exploit tremendous opportunities which the present day globally competitive environment offers, to be a leader of the knowledge based world economy emerging in the 21st century.

Indian economy is ranked 11th on Gross National Income (GNP) basis but becomes 159th in rank; if we convert it into GNP per capita basis (2009). The problem and solution to India's emergence as a global knowledge leader is contained in this statistics. As things stand today; due to low productivity of Indian manpower; the population seemingly is its current liability. However, if each of India's work force was an efficient; hard working; considerate, ethical and talented worker; the same population will become its major asset. Hence the need to reengineer the current business environment to make it globally competitive through high productive efficiency of our people, processes and systems. Let population be an asset rather than a liability, which is possible if each and everyone contributes to value addition and wealth generation.

2, Globalization and the Indian Economy:

India took the path of economic reforms starting in 1991 to interlink with the global economies. This can be a great opportunity if the global competitiveness ranking can reach the level of being in the driving seat; but it can be a major threat if Indian competitiveness level does not match up to the level of lead players particularly its neighbor in Asia - the China. In the past 20 years, the progress made by China defies all estimations or forecasts. Thus; India cannot think of incremental approaches to enhance its productivity, efficiency and competitive advantage if it has to be a leader of the global, knowledge driven world. It has to have a fundamental 're-think' and re-engineer its business environment; work culture; mind-sets of its people and rationalize its priority structure in goals and objectives in the process of nation building. Taylor's focus on rational decision making; fairness in wage compensation, using technology to enhance productivity, encourage high performance through incentives and focus on training and human resource development is very relevant even in this context. But passion and zeal is the basic Taylorian attribute we need to benchmark with.

Fortunately; the robustness of Indian economy got tested through the periods of global recession the world has seen in the past few years which had shaken some members of the economically developed world. However, Indian economy only slowed down and still registed 6 - 7% growth of GDP. This remarkable turnaround and recovery of the economy from global recession has been widely acknowledged. Table 1 shows the macro economic trends in the GDP growth since 1980's. While industry growth is at 8.3% and services at 9.3% which indicates the broad based nature of the economic recovery; but a low growth rate in agriculture and in manufacturing is a worrisome feature reflecting 'imbalance in the growth profile'. This poses a major problem which needs to be addressed. While manufacturing seems to bounce back, agriculture has not.

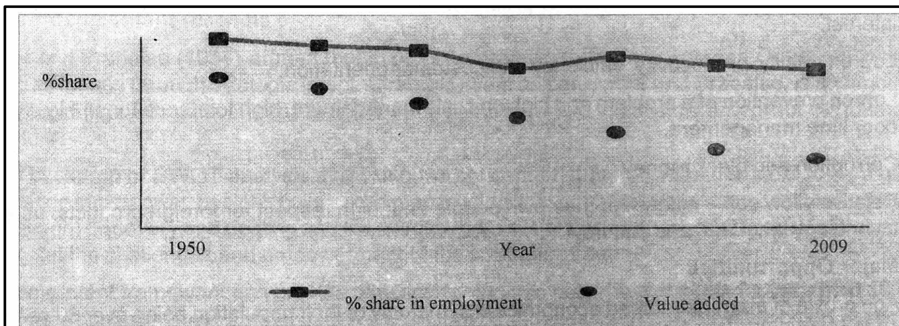
Table 1

Macroeconomic Trends : Growth Of GDP

Years	Agriculture	Manufacturing	Industry	Services	Total
1980s	4.4	6.9	6.2	6.7	5.6
1990s	3.0	5.9	5.81	7.6	5.8
1992-1997	4.7	9.8	7.6	7.6	6.7
1997-2002	2.1	3.8	4.6	8.1	5.5
2002-2005	0.9	6.7	8.3	8.4	6.6
2005-2006	5.9	9.0	10.1	10.3	9.4
2006-2007	3.8	12.0	11.0	11.1	9.6
2007-2008	4.6	8.9	8.5	10.8	9.0
2008-2009	1.9	2.5	4.0	9.7	6.8
2009-2010 : Q1	2.4	3.4	5.0	7.8	6.1
2009-2010: Q2	0.9	9.2	8.3	9.3	7.9

Source: NCAER, 2010

Fig. 1 is a time series analysis indicating % share of agriculture in employment and in value added. This reveals a major gap in the development profile where agriculture; which was a major employment generator has very little contribution to value addition. Agriculture and manufacting are two sectors where physical wealth is actually generated (Chadha, 2010). These have not grown so well. Intellectual wealth through research and innovation is another area where India's contribution is decaying if we compare the research publications in India and China over past 20 years. This context provided a basic stimulus to a thought process leading to proposing a critical re - appraisal of Indian development process; and to identify the gaps and imbalances it has created. A SWOT theoretic framework identifies the major strengths that can be leveraged and major weaknesses that must be overcome to have unhindered growth and prosperity.



Source : NCAER, 2010

Fig.1 - Percentage share of agriculture

1. A SWOT Framework of Indian Work Environment:

SWOT (Strengths, Weaknesses, Opportunities and Threats) is a powerful framework for corporate appraisal and soul searching. A preliminary SWOT analysis of India as a whole was attempted which revealed the following:

a) Major Strengths:

1. Demographic dividends with more than 55% people who are less than 25 years of age.
2. Intrinsically intelligent and innovative people.
3. Largest functioning democracy in the world.
4. Dedicated Parenting keen to give good quality education, to their wards even at the cost of their own comforts.
5. Rich Bio-diversity, great sunshine, large coastal line and rich natural resources.
6. Great Ancient Past in terms of knowledge, trade, values and culture.
7. Large scientific and technical manpower.
8. Good in analytical thinking mathematical modeling, software skills and language.
9. Best in the people comes out in adversity, during crisis situation or through in- centivisation.
10. Quick to adopt new technology if individual benefits are perceived recent cell phone revolution is a case in point.

b) Major Weaknesses:

1. Too much self - centered; much less concern for others.
2. Paradoxical nature of development - extreme diversity, imbalance and extreme variation in wealth distribution. Richest and poorest of the world co-exist.
3. Myopic - short sighted view in decision making.
4. Lack of ethical practices, self - discipline and self - control.
5. Poor quality of education and low employability.
6. Segmented, sub - systemic view of problems. Tendency to look at a problem from their own interest.
7. Low on quality, productivity, efficiency and customer orientation.
8. Low on prevention of a problem and high on crisis management, high tolerance for ambiguity and poor time management.
9. Corruption and black money.
10. Relatively low self - esteem of their own people and; high respect for foreign products; people; technology language and culture.

c) Major Opportunities:

1. Age profile of many developed economies with majority of their population being over 60 years of age and low growth rate of population. This will generate demand for Indian Talent abroad.
2. Information technology and knowledge based economies.
3. Education, R&D, Health hospitality and Spiritual tourism potential of India.
4. Knowledge products export.
5. Renewable energy sources.
6. Exploiting rich bio - diversity for sustainable development and earning carbon credits.
7. Leverage coast line and rivers / canals for water transportation.
8. Identify niche areas and reengineer to make Indian manufacturing sector globally competitive.
9. Focus on infrastructure development to match world class standards.
10. Improve public - distribution system, logistics and supply chain through IT .

d) Major Threats :

1. Corruption resulting in black economy, fake currency and illegal practices.
2. Intolerance, extremism and terrorism.
3. Extreme variations in almost all aspect of life - in wealth distribution, quality, productivity, with palatial housing and slums co - existing. World class to third class institutions and products.
4. Caste based politics; traditions.
5. Complacency in a competitive environment.

6. Large unemployable youth population.
7. Emergence of strong global competitors such as China.
8. Job seeking mindset rather than job creating.
9. Low enforcement of rules of law; tendency to short circuit norms and processes to gain personal benefit.
10. Global warming and unpredictable climatic variations.

The SWOT - analytic framework helps in identifying a roadmap for strategic intent by exploiting Indian core competence and strengths; overcome weaknesses treating each weakness to be an opportunity to improve. Exploit opportunities that global and knowledge driven world provides while guarding against threats that can block the progress and India's march towards global knowledge leadership.

2. Strategic Intent for India:

Hamel and Prahalad (1994) argued that in order to achieve success, a company must reconcile its end to its means through strategic intent. Strategic intent as per Hamel and Prahalad, is an ambitious and compelling dream that energizes and provides emotional and intellectual energy for the journey to the future.

In the backdrop of SWOT analysis and using the concept of strategic intent for India to be a global knowledge superpower, one can build a road map towards that goal. Strategic intent has three attributes of direction, discovery and destiny and the process consists of three important steps: set the strategic intent, set the challenges and empowerment of the strategic intent.

Strategic intent framework can provide direction for India to become global leader over next 10 – 20 years time horizon. The dramatic post - war ascent of Japanese companies in which an obsession to win was created and sustained at all levels of the organization to achieve the goals that looked unrealistrc with regards to resources and capabilities. Strategic intent is a high level statement of the means by which an organization can achieve its grand vision. It is also top management's primary motivational tool for radical idea generation. Expression of strategic intent is to help individuals and organizations share the common intention to survive and extend themselves through time and space. It focusses on tomorrow's opportunities and is effective in new and unstable business environments and builds on new opportunities leveraging inherent core competences. Without passion and zeal to realize strategic intent; vision statement becomes an exercise only on paper.

The new stretched goals for India have to be the global knowledge leadership with a high quality of life to all its people and acknowledged knowledge leadership globally. This calls for an emotional appeal to have passion and zeal to enhance efficiency, effectiveness, quality, productivity in all aspects of national economy and to have a balanced developmental score card removing glaring inequalities and extreme variations in quality of life. It calls for overcoming weaknesses and have a shared perception of development goals and demonstrate effectiveness of Indian thought leadership.

In doing so, there is need to have the passion of Taylor, who with single mindedness and despite strong opposition from some quarters pursued the path of rationality and scientific approach to methods and techniques to enhance productivity and manufacting efficiency. Thus, using the model of strategic intent; coupled with passion of Taylor in implementing it; a roadmap is proposed for India for achieving global leadership role in the following sections. This can only happen through reengineering Indian business.

3. Reengineering Indian Business Environment:

Michael Hammer and James Charnpy (1994) proposed the concept of reengineering to bring revolutionary changes in a corporation as opposed to evolutionary changes. Business process reengineering is a set of procedures to affect radical changes; doing things in a drastically different manner. To achieve great heights; one should be willing to absolutely discard the present for the new. It is "a fundamental rethinking and radical redesign of key business processes to achieve dramatic improvements in critical contemporary measures of performance, such as cost, quality, service and speed."

One needs to not only reengineer the process, but also the people development, leadership and technology. In fact it is the coordinate development of people, process, technology and the leadership that together can make radical changes and progress possible. Taylor had proposed stronger focus on systems than man with the main objective of systems to develop first class people.

Combining the passion of Taylor to be forceful in implementation; and strategic intent concept of Hamel and Prahalad for India to be the global knowledge superpower over next 10- 20 years; it is surmised here that India needs to radically change its priorities; styles, value system and attitude towards work and customer. This calls for reengineering approach; pursuing directions suggested by SWOT framework to realize great Indian vision through strategic intent with a passion of F.W. Taylor to implement. Prahalad gave a major academic recognition to Indian intellectual genius through his concept of strategic intent.

This model framework and focused self brainstorming has resulted in a 21 - point strategic roadmap. This roadmap; if implemented through a shared perception and a common dream to make India a developed nation and a knowledge superpower over next 10 - 20 years; can lead to unbelievable results. This is because India has the core strength and Indians have great minds; what it needs is equally matching great mindsets. If this happens; India will definitely be getting back to its past glory when India accounted for nearly 27% of world trade and knowledge seekers from all over the world used to come to India to study in great knowledge centres of Nalanda and Takshila. These 21 – point strategies are the basic e-mantras that can give leadership role to Indian economy. Since the focus is on 'Economy' and 21st century; these 21 e-mantras start with letter 'E'. The remaindes of this paper outlines these strategic roadmaps. Mintzberg (1994).

4. The Strategic Roadmap Proposed:

The 21 - point strategic roadmap or e-mantras to enable India to become knowledge leader in the 21^{st} century are listed as follows:-

i. Elephant Analogy or Systems (holistic) approach to problem solving-

There is a need to perceive an elephant as an elephant and not through its body parts. In the absence of an integrated approach, different stake holders look at the same problem quite differently. This leads to chaos, confusion and people pulling in different directions. Many problems that are encountered today are the outcomes of this narrow sub-systems thinking. A transformational change of mind-set would look at the problems in its totality. This will lead to a balanced approach to development. An elephant analogy also looks at Indian economy through positive attributes of its size, strength, stability, memory and intelligence. Through holistic approach and efforts, can bring agility to the economy and make the elephant dance.

ii. Education-

A fundamental rethink and change of mind-set on education is called for. Investment in education is to be perceived as investing in the nation building process. Objective of education should be to develop value based global mindset; and create good human beings in addition to be good professionals, academics, researchers etc. An integrated view of education will attempt to nurture 'Indian Talent' who are globally employable. Demographic dividend is only possible through good quality education. Educational institutes should be seen as nursery of India's future talent pool. No investment is too much for education. However it is opined here that as an investment in the nation's future at least 10% of national budget should effectively be spent on good quality education.

We also need to relook at the role of teachers, who are perceived as role models by students and need to create an environment where brilliant scholars with inspiring communication skills and exemplary value system take up teaching as their preferred career option. Role of teachers should be to "Inspire -Involve - Transform" (IIT) the students. This calls for fundamental rethink on the part of society towards teaching profession - otherwise it will be a great loss due to missed opportunity of leading the knowledge driven globalized world. Demographic dividend will become a demographic liability if we cannot educate properly India's youth.

However education without good human values cannot lead towards a developed society. Hence value education should be an integral part of education at all levels so that we nurture India's youth to balance the concern for self with the concern for others. Fig.2 proposes a Value Grid for Value mapping of people. It is a perhaps a painful fact that if we try to fit it Indians into these four quadrants – majority will be in the 'individualistic' or 'indifferent' category. There is an urgent need to train the Indian population to be in 'ideal' category because 'iconic' personalities are arguably few.

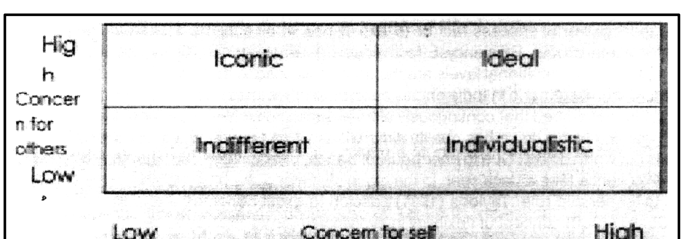


Fig.2. Proposed value Grid.

Due to low focus on value integration in education, institutions and its processes are developing people who rate high on 'concern for self' and low on 'concern for others'. As a result; TEAM (Together Everyone Achieves More) work is weak and MAD (Mutually Assured Disadvantage) syndrome is more commonly seen. This mind set is one of the major hindrances and must be changed to TEAM.

i. Energy-

Energy security and self - reliance are vital since per capita energy consumption is taken as a surrogate measure of development. In India; we need a fundamental rethink on energy sources. Traditional coal and oil based energy must give way to environmentally sustainable renewal energy sources such as solar, wind, biomass, geothermal, tidal, small hydro and possible nuclear based energy sources. India is a blessed nation with such a sunshine round the year. By economically exploiting solar energy, not only energy security is assured - perhaps India could be exporting surplus energy. However; so far only half - hearted efforts have been made to explore renewal energy sources. There is a need to reverse the focus - renewal first and oil I coal based only when there is no other alternative. Even in oil based energy; the focus should be to use gas as preferred source over oil.

Energy efficiency, energy conservation aspects are as critical if not more. Energy losses to the tune of 30-50% in generation, transmission and distribution are reported. Energy efficient, technologies, machines, equipments and facilities must get priority attention: fortunately 'star ratings' of electric equipment and efforts of PCRA in sensitizing people for energy conservation are laudable but much more needs to be done, Unless we ensure reliable, dependable, economic, safe and adequate energy to meet developmental needs; to aim at becoming a developed nation will be a mirage.

ii. Environment-

Ecological and environmental issues have to be concurrently addressed otherwise development will be adversely affected. There is such a concern for environmental protection globally, that without assuring environmental protection, developments is not possible. In India; a transformation of mindset is required towards waste management. Much of the focus has to be on 'prevention' of waste. Waste elimination, recycling, reuse and disposal will have to be aimed at preserving the environment and the ecosystem e - waste is a newer challenge due to electronic revolution. Reverse supply chain, green supply chain, carbon credits planning are the new areas for sustainable development. But waste management, energy conservation and environmental protection constitute the interrelated trinity.

iii. Excellence-

One of the most powerful success factors is 'excellence' in all aspects of manufacting and service operations (Vrat et al. 2009). Efficiency, Effectiveness; quality, productivity, excellence - at individual, team, process and organizational levels are the goals that need to be pursued with the Taylorian zeal and passion. Current scenario in India on this account is not impressive. A transformational mind-set is required to be developed that continuously aims at excelling whatever is done. Guiding philosophy has to be "anything worth doing has quality dimension in it and anything which does not have quality dimension is not worth doing'. Due to enormous tolerance for ambiguity and 'chalta hai' culture, quality, efficiency, excellence take a back seat. In the globalized world, such an outlook or mindset will never take India to leadership role. Taylor's (1911) passion to excel becomes a role model for everyone. However Sushil (2000) concept of flexibility in evolving strategic interventions is needed.

Excellence requires creating a nurturing, and enabling environment at work, recognition of outstanding performance and a transparent performance measurement system. Motivation and commitment are two important enablers of excellence. The following equation is often employed by the author to convey the impact of commitment on excellence:

$$E = M.C^2$$

Where E = Excellence; M = motivation; and C = commitment.

Obviously half - hearted approach (c=0.5) does not lead to excellence; but passion and zeal (c=2) does.

iv, Ethics-

Strong ethics, at the level of individual, family, team, profession, corporate and society at large are vital to gain global respect, acceptability and eventually; market share and customer retention. It is empirically known fact that in the long - run only ethical businesses survive. Short cut approaches compromising with ethics may show short - term miracles but in the long run these do not sustain. There are so many cases of corporate declines due to frauds and corrupt practices, which initially were being talked about with praise.

Rampant corruption, black money are some of the symptoms indicating lack of ethical practices. Only a strong sense of ethical behaviour on the part of everyone can transform India to become a knowledge super - power. In many global surveys; India ranks quite high on corruption index. Information technology can be leveraged to bring in greater transparency in business transactions. Right to information Act can be a great facilitator of greater transparency and resultant ethical behaviour.

v, Employability - Enhancement -

'Employability' of professionals and other students in India is perceived to be quite low. NASSCOM had recently estimated immediate employability of IT graduates to be about 25%. For general university education, it is even lower. With such a low employability; demographic dividend will become demographic liability. India's claim to become a knowledge super- power will never be realized unless employability is enhanced to almost 100% level. Unemployable youth can create unrest in the society. Hence a fundamental strategic rethink is needed to maximize employability. With high employability, employment will come but with low employability even if an employment is obtained, it may not be sustained.

Employability is a composite of knowledge, skills and attitudes. The following equation is proposed to relate these three causal variables to the goal of employability.

$$Em = A[\alpha.K+(1- \alpha)S]$$

Where Em = employability index between 0-1.

A = Attitude between (0-1)

K = Knowledge index for the intended purpose (0-1)

S = Skill Index required for the intended purpose (0-1)

α = relative importance to knowledge, between 0-1.

α will depend on the nature of job. For vocational level, á will be low, for research and development á will be high. Attitude, as a critical success factor is multiplicative. With negative attitude (A=O); a person may not be employable at all even if he is knowledgeable and for skilled.

vi. Encouraging Exploration & Innovation -

It is a major paradox that as individual, Indians are very innovative but at national level the innovation index is low. In the recently published Global Innovation Index (GII) statistics, India ranks 56 among nations with a score of 3.06 on a 5 - point scale on global innovation index. Indian concept of 'Jugaad' is a manifestation of individual creative genius to find quick, low cost solutions to problems (Krishnan 2010). India needs to encourage innovation and capacity to 'think out of box'. Research & Development creates product innovations and hence new markets. At present however, Indian industry and even universities are not devoting enough resources to research and innovation: research like teaching is a low priority career option in India, which in the long run will affect the global competitiveness of Indian industries. Industry, except very few, hardly are spending on R&D. As a result, openings for M.Tech. 's and Ph.D.'s in engineering and technology in industry are few and not very attractive. This in turn is adversely affecting postgraduate and research programmes in attracting the best talent to these courses and a 'Syndrome of diminishing calibre' seems to be in evidence as one goes to higher degree programs in engineering and technology, in particular. Research may not give immediate result, but in the long run its return on investment is quite high. It is proposed here that the industry must spend at least 5% of its sales turnover on Research & Development for product and process innovation. A fundamental change in mindset is called for towards research and innovation to lead in a globally competitive world (Khandwalla, 1988).

vii. Export of Knowledge Products and Expertise -

India's trade imbalance is on the rise after liberalization of the economy. This imbalance was -6.5% of GDP in 2000-07, -7.4% in 2007-08, -9.8% in 2008-09 and is likely to be -10.2% of GDP for the year 2009-10. Thus there is an urgent need to increase Indian exports. Perhaps in manufacting sector, it will take more time to take lead over China, which seems to have dominated world markets. Indian productivity, quality and infrastructure do not yet support manufacting excellence, though in the long run there is need to focus on it. However, taking India's core competences in analytical ability, superior modeling and software programming skills, good English language skills, flexibility to adopt in alien and difficult environments and putting enormous hard work to survive in alien environment if it can lead to making quick money, Indian exports focus should be on the knowledge products as well as export of its globally employable Indian Talent (IT). Thus, in the short to long term basis the focus of exports should be on: softwares, books, journals, periodicals, KPO's, modeling and algorithms, CD's, films, artifacts, paintings, contract research, consultancies, and professional expertise. An Indian cuisine is another potential exportable commodity. 'Indian managerial talent to manage companies outside India can earn remittances almost at par with export of commodities. In general, there is a perception that Indians do extremely well outside India. Let this be a major strength for India, India needs to revisit the concept of so-called "brain drain."

viii. Equitable Distribution of Resources -

Indian society exhibits extreme contrasts. The most rich in the world and most poor people co-exist here. This inequitable resource distribution is not a sign of great society and is not a sustainable proposition for peace and all round prosperity. Until this extreme inequity is addressed; India cannot possibly be a world leader. No leading economies in the world have this extreme variation of wealth distribution. Contrast can be seen between currently topical IPL and BPL. IPL Pune team was reported to have been purchased for Rs. 1702 Crores, while 37.20% of Indians are below the poverty line (BPL) with Rs. 20 a day to sustain.

Even from the point of view of higher quality of life (QOL), extremely low or high degree of wealth is not a desirable proposition. Fig.3 depicts the hypothesis that QOL and wealth have a 'bell shaped' relationship and extremes (both low and high) result in low QOL and there is an optimal level of wealth to maximize QOL. Equitable distribution reduces the range of the curve and makes it flatter. With reduced inequality, overall quality of life goes up. It is sometimes opined that India is not a poor country; perhaps, it is a poorly managed one. .

Extreme salary differentials between CEO's and the lowest paid employee in a company could lead to erosion of industrial relation climate. In Japan this ratio is in the range 8-10; whereas in some Indian corporate world it could be as high as 200. However it is emphasized here that equitable does not mean equal. It should be fair and rational. This is what F.W. Taylor strived for in his life - Fair days wages for fair day's work.

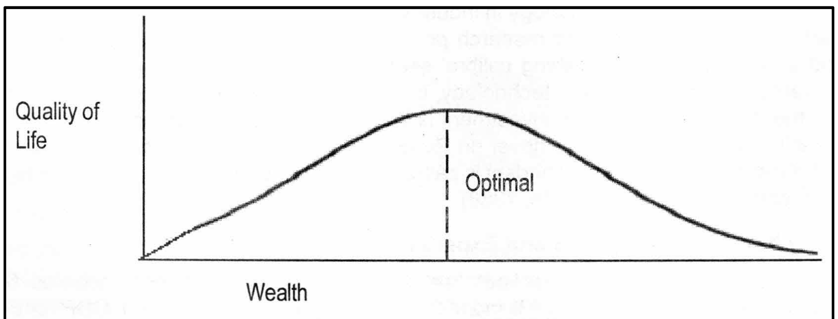


Fig.3. Quality of Life as a Function of Wealth

xi. e-Governance-

e-governance can transform the way India manages its administrative, managerial and corporate affairs. With the advent of information technology, a fundamental rethink of key business processes is needed to make them IT - enabled. Internet, mobile communication and other ICT's have enormous role to improve efficiency, reduce delays, reduce inventories, reduce response times and increase customer satisfaction. e-governance can bridge the gap between rural and urban India. e-procurement, e-tendering can reduce lead times and minimize collusion among bidders. This strategy is so vital to India's progress and for curbing corruption; that even if legislative measures are needed to make it obligatory, it should be done. Of course to facilitate smooth implementation, negative side – effects and influences, cyber-crimes and malpractices have to be kept under control. People mind-set must become compatible with technology.

xii. e-Learning-

Learning is a vital strategic intervention to quickly reach a wider cross section of Indian society for delivering quality education. Given a low GER of 12% in higher education and acute shortage of talented and committed teachers; e-Learning can, in a supplemental role as well as stand alone mode is a powerful enabling technology. It could be in either Just - in - Time (JIT) mode or made to stock(MTS) through cd's and dvd's. It is economical, affordable and has a wider reach of education. Virtualization of technical education can overcome faculty crunch to some extent. NPTEL scheme of MHRD was a good initiative in this regard. However much more needs to be done on this front.

However issues like technology dependability, capital investments, change management, quality of delivery and guarding against unethical practices in the use of internet, web and cell phones need to be addressed.

xiii. Entrepreneurship -

Individually Indians are quite enterprising and can quickly adopt a technology if it is advantageous. They are quick to find opportunity of doing business in every difficulty, shortage and problem situation. However their mind-set is that of a job-seeker and not an entrepreneur - a job giver. Silicon Valley in the U.S. was a phenomenal success due to Indian and Chinese entrepreneurship genius. A major rethink is needed to encourage, nurture and promote entrepreneurship over job seeking. This can be done by sensitizing people to use their native enterprising spirit and create and put in place enabling environment, rules and policies. It must be ensured that bureaucratic delays, hurdles and corrupt practices do not dampen or dilute this spirit. A recent survey of CII indicates that on the basis of average time to register a company, India ranked 8151 as compared to 9th rank of USA. Thus there is a need to simplify rules, proactively support potential entrepreneurs about opportunities and threats associated with various business propositions. IPR support and idea incubators and venture funds must be strengthened in a big way to convert an idea into a viable product and turn job seekers into job -givers.

xiv. Exposure to Best Practices -

Benchmarking with best practices or emulating the role model is an effective and quick method of transformation. This saves time, money and risks associated with direct experimentation with reality. This calls for wide global exposure but caution is advised in selecting the best practices which can be from any place or source: local, regional or global. Blindly transplanting a practice, even if it had done well elsewhere is no guarantee for it to succeed in Indian context. Hence there is a need to cultivate the culture of information sharing and an open mind to adopt the most suitable best practice. Benchmarking can be powerful process in reengineering (Champy, 1994).

xv, Expenditure Controls -

Despite low wages, the 'delivered-cost-to customer' is not very competitive in India due to low productivity, low quality, high wastages of resources and lack of preventive focus on cost avoidance. TQM approach on Cost of Quality and Value Engineering are not extensively being employed in Indian manufacting and service. There is an urgent need to employ Pareto's Law or 20:80 rule and control chart theoretic approaches to effectively control costs and avoid wastages. Materials account for nearly 60-70% of manufacting costs, yet scientific approaches to materials management are not quite common; while manpower costs being only 5-10% get so much attention. Cost accounting system must change to employ the cost of Quality - either PAF model or POC - PONC model to capture a" relevant costs - both visible and hidden for effective cost avoidance, cost reduction and control.

xvi. Enforcement of Law -

Effective implementation of a plan, policy, rule, law or norm is perhaps the weakest link in Indian competitiveness. As a result, many attempts to alter the scenario through policy intervention do not lead to desired result. Compliance of rules is not high. There is a wide gap between intentions and actual accomplishments. Effective grievance handling, quick delivery of justice and enforcing implementation of rules is a pre-requisite-for India to lead the knowledge world. Perhaps fewer rules and effective enforcement is better than too many rules and low enforcement rate.

xvii. Evolve Right Goals Priority -

Since most decision making is under 'Multi - Criteria' context; correct, and rational prioritization of goals is of vital importance for rational choice. With wrong priorities; even with adequate resources and intentions; one gets into trap of poor goal accomplishments. There is a full fledged field of 'MCDM - Multi Criteria Decision making' and techniques like decision matrix and AHP can be quit helpful in evolving rational goal priorities. Perhaps higher priority to infrastructure, energy, water, education, health and excellence ,efficiency and efficacy is required to achieve the goals of development.

In the absence of rational, scientific approaches to evolve right priority structure of goals; one may focus more on trivial issues and ignore the vital or primary objectives. Thus a scenario of "Misplaced Emphasis Syndrome "may prevail, when means might become end-in-itself or tertiary goal may dominate over primary goal. This must be prevented so that priority goals are accomplished well.

xviii. Empowering People -

Excellence driven organizations and countries develop and empower their human resources. Unless everyone is committed to the cause; accomplishment will be lacking. Therefore in the spirit of TQM; involve everyone from 'top floor' to 'shop floor'. Thus create Theory 'Y' like conditions by constantly training, developing and empowering people and decentralize decision making process. Jidoka system in Japan, empowers a shop floor worker to stop the whole production line if the process is malfunctioning. There is a need to empower the weak, women and wise people in the society. However, empowerment calls for integrity, wisdom, honesty and sincerity of purpose and placing nation before self. This calls for effective HRD policies through role model teachers and leaders.

xix. Empathize with Customer-

Globalization is a customer driven phenomenon. However, Indian Customer Orientation is weak in majority of situations. If India is to lead; this must change. Hence strategy of driving organizational decision making which are customer centric is vital. India needs to follow the Gandhian dictum on customer orientation as according to him "A customer is the most important visitor to our premises. He is not dependent on us, we are dependent on him. He is not an interruption in our work; he is the purpose of it. He is not external to our business, he is a part of it. We are not doing him a favour by serving him; he is doing so by giving us an opportunity to do so". Therefore India just needs to look at the customer from the Gandhian lenses and see Indian global competitive advantage increasing.

xx. Evaluate Alternatives in a Life Cycle Perspective-

Indian business is generally myopic and evaluates various decision alternatives on a short-term basis. Often it leads to a wrong choice or focus. As Forrester (1971) opined - short term view of a problem may negate long term solution of that problem. What looks appealing in the short run may ruin the system in the long run, when solution prescribed is worse than original problem. Hence adopt a 'Life Cycle Costing' (LCC) approach and these costs should include both hidden and visible, tangible and intangible costs. This perspective will ensure right choice being made in the long term interest of the system. This is what differentiates visionary leadership from others.

xxi. Eye for the Details -

An eye for details is vital pre-requisite to achieve goals. Due to lack of this, a great plan gets stuckup on account of a trivial oversight. A good leader - manager is strategic in thought but has a tremendous capacity to look at the details while implementing that decision. In India; generally due to lack of eye for details; great ideas and projects do not get realized in time even if the intentions are sincere; because some unforeseen trivial problem comes in the way of effective implementation. A detailed operational plan with an eye for details and identification of possible difficult spots with remedial action and contingency plans can help realize the strategic intent. Poka-Yoka system where even by mistake one can not commit a mistake can help. An eye for details enhances performance and does not diminish the strategic role of a manager.

7. Concluding Remarks

This Taylor memorial lecture; inspired by the spirit and passion of F.W. Taylor for maximizing productivity through rational and scientific approaches has attempted to present a strategic roadmap to realize the strategic intent of making India a developed nation and the leader of knowledge driven society. In the process; it has proposed a 21-point strategic interventions; all starting with 'E' which use Indian core competences; attempt to overcome inherent cultural impediments to realize the grandiose India vision. Of course, many ideas proposed here are postulates, conjectures and/or hypotheses on which further work needs to be done to validate these assertions. By overcoming developmental barriers in Indian business environment, much more progress can be made. As the concept of strategic intent involves passion, zeal and commitment to achieve these stretched goals; it can only happen if everyone shares these passions and is led by the champions of change.

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Sustainable Manufacturing — Principles, Applications and Directions

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Abstract

The current rate at which humans are utilizing the earth resources is not sustainable and it will be affecting the environment in a number of ways. Responsible behavior for humans is to utilize the available resources in a way such that the environment will not be affected such that future generations of humans will enjoy the same quality of life that we are currently having. Manufacturing being a very resource consuming activity, it is important to consider sustainability at all levels of the life cycle of the products that are manufactured. This paper presents the definition of sustainable manufacturing as an activity that embodies those principles. Life cycle analysis is an accepted method to identify the environmental impact of the manufacturing activity. In order to incorporate environmental requirements into manufacturing practices entirely different way of thinking needs to be practiced by researchers. Sustainable manufacturing is now a realizable goal and a number of areas within manufacturing are benefitted by it. The research involves in reducing the energy requirement for manufacturing processes and practices, as well as using materials that are more environmentally friendly. Already very promising results have been achieved in a number of areas. A summary of the past research in various sustainable manufacturing practices is presented that provides a direction in which research in sustainable manufacturing can be achieved.

Keywords Green manufacturing, Sustainability, Environment

1. Introduction

It is a fact that in the past 50 years, humans have consumed more resources than in all previous history. Between 1950 and 2005, worldwide metals production grew six fold, oil consumption eight fold, and natural gas consumption 14-fold. In total, 60 billion tons of resources are now extracted annually - about 50%more than just 30 years ago. Today the average European uses 43 kilograms of resources daily, and the average American uses 88 kilograms. It is a fact that this rate is not sustainable, and if we would like our future generations to enjoy the same type of environment and resources, then the mankind need to address this problem as soon as possible. The harmful effects of our consumption and its final impact on the humankind are known [1, 2]. Various governments, national and international agencies have been making efforts to generate strategies and action plans to educate the people and organizations to strive towards this goal as soon as possible.

For example, US is taking initiatives to play roles in pursuing green manufacturing through more strict regulations from government while getting commitment from business community. "Green Jobs in Manufacturing" strategy becomes very important, because it will help to turn into a long term success due to a healthier community, increased resource efficiency and effectiveness, waste minimization, risk mitigation [3]. Pursuing green manufacturing must be a global issue in order to protect Earth - home of all human beings. Globally, Europe, Asia, USA, South America and even the UN are developing more regulations, penalties, tax benefits or obligations to become greener.

Japan took early initiatives in terms of implementing lean manufacturing, recycling/reusing resource because of limited domestic resources. In 2009 China invested $34.6 billion in the renewable energy sector. China also became the world's biggest maker of wind turbines in 2009 and the largest solar panel manufacturer in 2010, accounting for one third of the world's solar panels [4]. The Renewable Energies Act in 2000 of Germany pays any company or individual who sold back renewable energy to the grid. In 2000, the German government set an objective to generate 12.5 percent of its electricity from renewable sources by 2012; it attained that level five years early. A new goal to achieve a 20 percent level by 2020 likely will be achieved in 2011 [5]. In countries such as Denmark, Germany, Norway, Sweden, and in high environmental risk industries (chemicals and plastics, automotive, heavy engineering), managers consider improvements in environmental performance one of the basic competitive priorities, along with lower costs and production lead time or higher quality.

Thus it can be seen that a large and sustained effort is maintained all the global players to make sure that environment is given priority over all other factors. Manufacturing is highly energy intensive industry.

Manufacturing systems though create material wealth for humans; they consume a great amount of resources while generating a lot of waste. The waste generated during the manufacturing processes, during the use of the products and after the end of the life of the products is responsible for the degradation of the environment. To minimize the resource consumption and the environmental impact of manufacturing systems has become increasingly more important. In USA, according to the Govt. estimates, manufacturing consumes about one-third of the total energy used in the country. Therefore it is imperative that manufacturing industries need to strive for "Sustainable Manufacturing" on their part. This paper reviews various attempts made worldwide about sustainable manufacturing in a number of ways and presents systematic methods that could be applied to reach this goal.

2. Definitions

Sustainable manufacturing has many names used by various people such as Green engineering, Green manufacturing, Clean manufacturing, Environmentally conscious manufacturing, Environmentally benign manufacturing, Environmentally responsible manufacturing and Sustainable. manufacturing. Sustainable manufacturing or Green manufacturing for our purpose can be defined as a method for manufacturing that minimizes waste and reduces the environmental impact. These goals are to be obtained mainly by adopting practices that will influence the product design, process design and operational principles. A more inclusive definition according to Melnyk and Smithis [6, 7], "it is a system that integrates product and process design issues with issues of manufacturing, planning and control in such a manner as to identify, quantify, assess, and manage the flow of environmental waste with the goal of reducing and ultimately minimizing environmental impact while also trying to maximize resource efficiency". The goal of responsible manufacturers should be to design and deliver products to the consumers that have minimal effects on the environment through their manufacture, use and disposal [7].

According to the United States Department of Commerce - "Sustainable manufacturing is defined as the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers."[8]

Ricoh the copier company defines sustainability [10], in terms of development and progress, as follows: "We are aiming to create a society whose environmental impact is below the level that the self-recovery capability of the natural environment can deal with." They give a simple example to explain: "For example, the reduction target of CO_2 emissions is generally based on the 1990 emission level, but in the future we need to limit emissions based on the estimated emission level that the self-recovery capability of the Earth could deal with."

Therefore any definition that we may like to use for Sustainable manufacturing should include all the ideas from the various definitions be incorporated. A proposed definition for sustainable manufacturing is

"a system that integrates product and process design issues with issues of manufacturing, planning and control in such a manner as to identify, quantify, assess, and manage the flow of environmental waste with the goal of ultimately reducing the environmental impact to that of the self-recovery capability of the Earth could deal with while also trying to maximize resource efficiency."

Now let us see how this has been achieved or planned to achieve.

According to Melnyk et al [7] compared to the worst Green Manufacturing companies, the best Green Manufacturing firms reported:

- 16.7% higher operating income growth,
- 13.3% higher sales-to-assets ratio,
- 9.3% higher sales growth,
- 4. 5% higher earnings-to-assets ratio,
- 3.9% higher return on investments,
- 2.2% higher return on assets, and
- 1.9% higher asset growth.

Champions of Green Manufacturing believe everyone is inherently interested in Green Manufacturing and would d more if they were:

• properly educated about its benefits and costs,

• made aware of the benefits being generated, and

• given access to the right set of tools and measures.

However, these views are often not shared by the users. In many cases, users see pursuit of Green Manufacturing as contrary to their own interests. There are several reasons for this view:

• users see Green Manufacturing as being another fad,

• users are not measured on their performance on Green Manufacturing,

• if they emphasize Green Manufacturing in their work, they will adversely affect their performance in lead time, cost, quality, or flexibility (areas in which they are measured and evaluated),

• the link between Green Manufacturing and cost, quality, lead time, and flexibility have not been clearly established,

• the pursuit of Green Manufacturing is seen as significantly increasing their workload with little or no real increase in benefits, and

• there is an environmental department, and Green Manufacturing should be its responsibility and not the responsibility of the users.

Similarly for Indian industries Sangwan [11] reported based on a survey of 198 Indian SMEs the following results: "The final quantitative benefits of green manufacturing in order of their decreased ranking are improved morale, improved brand value, lowered regulatory concerns, increased market opportunities, improved product performance and decreased liabilities. The quantitative benefits of green manufacturing are related to either waste (reduced waste handling cost, lowered waste categorization cost, reduced waste treatment cost, reduced waste disposal cost and reduced waste storage cost) or life cycle of the product (lowered transportation cost, decreased packaging cost, reduced overall cost of the product, lowered cost of production, reduced user operation/ use cost, lowered maintenance/ service cost and reduced overall cost to the organization)."

3. Life Cycle Analysis (LCA) and SM

The tool generally used to implement SM is the Life cycle analysis [12- 17]. It is an approach to examine fully the environmental impact of different activities performed by humans including the production of goods and services by corporations. LCA can be applied for any activity that is either at national level or global level in order to identify environmental burdens resulting from the activities of a society, region or industrial sector[12]. In fact LCA can provide an excellent insight for the engineer to study any given product such that he/she can identify the methods to reduce the environmental impact of a specific product or process[18-21]. A schematic of the methodology employed for carrying out the LCA is given in Fig. 1.

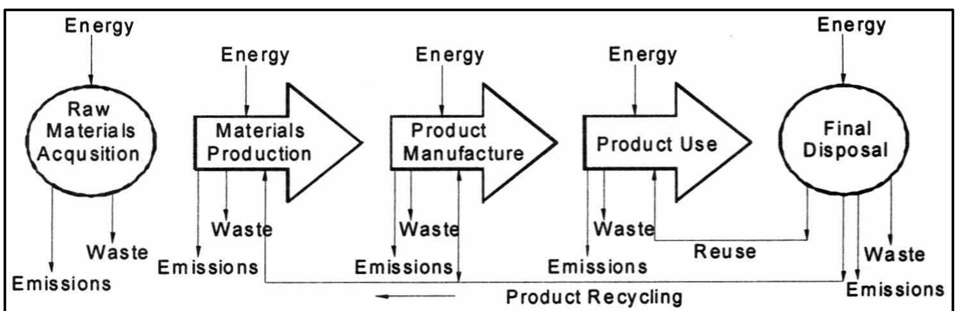

Fig. 1 Life Cycle Analysis

LCA is concerned with identifying the environmental impact of a given product or process at each of these life stages. Full implementation of LCA allows the engineer to make a quantitative comparison of the stages of a product's life, determine where the greatest environmental benefit is to be gained, and ultimately monitor the long term effect of changes in design and/ or manufacturing.

Let us take a simple example to illustrate the point of how the consideration LCA makes a very strong contrast to what we normally think about the environmental impact of the products. Let us consider clothing as an example. The energy consumed during the production of an article of clothing (making of yarn, making of the individual product, marketing of the product), energy consumed during the use of the product in terms of the water consumed, either hot or cold, detergent consumed, electrical energy for washing and drying, and the energy consumed to make the detergent used. The energy consumed in manufacturing an article of clothing makes up only 18%of the total energy consumed while the majority of energy (79.5%) consumed during the product's life is consumed during cleaning with the remaining energy being consumed in the manufacture of detergent [20]. As can be seen from this simple example it is clear that the biggest impact is to be made at the consumer use life stage. In order to reduce the environmental impact of clothing the approaches that were taken are developing fibres for clothing that can be cleaned in cooler water, reducing the energy needed to heat water; using fibres that dry faster; designing clothing to require lower concentrations of detergent; and labelling clothing to recommend the use of cold water and line drying. All of these activities involve engineering input and decision making.

The ISO standards [15, 22] assume a process based LCA approach and is organized into four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation as shown in Fig 2. It is important to understand the goals of the LCA and the methods to achieve them. Though this is a framework, the way the goals are formulated the work involved is going to be enormous. The deeper the level of analysis better will be the understanding. That will also provide better solutions to achieve the required results. However this will also call for a lot of effort from the user. Therefore during the first step appropriate scope should be defined. This will be followed in the second step to develop a quantitative analysis of the material and energy inputs to the product or process at all levels be made. In this it is also important to measure the possible environmental releases are also made. Here in the problem though our interest is to find the actual releases over the entire life cycle, the designer / engineer will only have limited knowledge or control on what the user of the product will be doing.

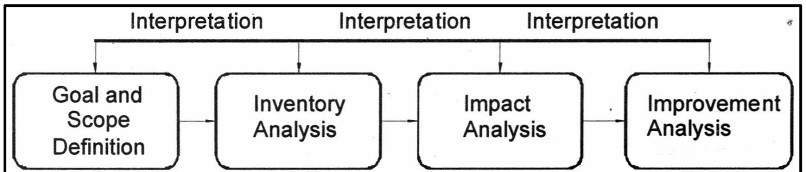

Fig. 2 The framework for Life Cycle Analysis

In the third step, the outputs of the system at each stage are related to direct impact on the external world. The trouble with this stage is that data that will be generated is controversial, incomplete or wholly unavailable. Also many of the impacts will depend on global and not necessarily regional in nature. For example the release of CFC's into atmosphere. As a result, data for this step is often qualitative in nature. The last step in the process utilizes the findings from the three previous steps and makes recommendations for the environmental improvement of the product or process under consideration. Ideally this information provides direct input for proactive approaches such as design for the environment initiatives.

A typical framework to study the life cycle costs is given below [23].

	Product life-cycle									
	Start up		Production		Distribution		Use		Disposal/recovery	
	Physical impact	Costs	Physical impact	Costs	Physical impact	Costs	Physical impact	Costs	Physical impact	Costs
Amount of waste										
Soil pollution										
Waste water										
Air emissions										
Noise										
Energy consumption										

4. Discrete Part Manufacturing

Manufacturing systems moved from craft production, to mass production in the early period with the developments in hard automation. In the last century the manufacturing systems have experienced enormous changes based on the various developments in machine tools, control systems, man-machine interfaces and decentralized control architectures. In the early part of the last century, major emphasis for technology development is towards low cost, high volume and low variety production. Later the market for the products has widened with the consumers demanding a large variety of products with economic uplifting of a large middle class. Couple this with the developments in microelectronics and the development of a variety of technologies and machines has made the life of the product limited. In the later part of the century the demand for large variety, low cost and high quality products are desired by the society. This means modularizing and standardizing in order to reduce the product development time and cost. As the time changed and the situation demanded the manufacturing industry had to adapt it to the new situations by changing the paradigm. The changes in the manufacturing paradigm during the last century with developments in technology, societal pressures and environment requirements as shown in Table 1 [24].

Table 1
Evolution of production paradigms [24].

Paradigm	Craft Production	Mass Production	Flexible Production	Mass Customization and Personalization	Sustainable Production
Paradigm started	~1850	1913	~1980	2000	2020?
Society Needs	Customized products	Low cost products	Variety of Products	Customized Products Globalization	Clean Products
Market	Very small volume per product	Demand > Supply Steady demand	Supply > Demand Smaller volume per product	Fluctuating demand	Environment
Business Model	Pull sell-design-make-assemble	Push design-make-assemble-sell	Push-Pull design-make-sell-assemble	Pull design-sell-make-assemble	Pull Design for environment-sell- make-assemble
Technology Enabler	Electricity	Interchangeable parts	Computers	Information Technology	Nano/Bio/ Material Technology
Process Enabler	Machine Tools	Moving Assembly Line & Dedicated Machining Lines	FMS Robots	RMS (Reconfigurable Mfg. Systems)	Increasing (additive) Manufacturing

We will be interested to discuss in this paper about the discrete part manufacturing. Discrete part manufacturing processes may be defined as production processes that are used to produce individual parts as output that can be identified and is measurable in distinct units rather than by weight or volume as in process industry. In the current scenario, manufacturing activities can be considered as being composed of multiple levels, from the level of the individual machine tools where unit processes take place, through to that of the enterprise, incorporating all the activities in the manufacturing system, including supply chains [26]. All these processes can be divided into five levels based upon their activities as follows:

• Individual Equipment: The actual devices or machine tools within the manufacturing system that is responsible to perform a process. All the support equipment required for that process is also to be included here, e.g., gage systems and device level oil-circulating systems.

• Components: The number of manufacturing devices within the system that are acting to execute a specific activity (such as manufacturing a part or assembly). Again all the supporting equipment to run such a system are also to be included here, such as chip conveyers and tool cribs.

• Facility: This covers all the equipment that is logically organized into lines, cells, etc. all of which is located in a single location. All the support equipment required to operate the facility level such as water, power, and HVAC systems are included.

• Enterprise: Different facilities that are under the same management whose proximity to one another allows them to make use of possible synergies in terms of reuse of waste and lost energy streams.

• Global: The entire manufacturing system, consisting of the enterprise with all its individual facilities, their vendors and all the other necessary the infrastructure required to support it.

The application of green manufacturing principles is valid at all these levels.

• Individual Equipment: At the individual equipment level we will be interested in optimizing operations of the equipment, minimizing the energy utilized, minimize the waste generated and utilize the materials that are environment friendly and not harmful to either the operator or the equipment involved. Involve the use of various sensors to monitor the process so that continuous optimization of the process can be carried out achieving all the above objectives.

• Components: At this level, interested in organizing a range of equipment which is organized into a line or a cell to produce a component or an assembly. The individual pieces of equipment present will be following the level 1 protocols. In addition to that, these systems would have the additional functions of scheduling, and information handling which can be termed as micro planning to be done at the cell or line level. There is a necessity to link this with outside in terms of material transport, tool crib, intermediate storage, etc. all of which need to follow the environment friendly practices.

• Facility: This having covered all the cells, lines and divisions under a single roof need provide macro planning to control all the activities. These should include product design, process design, production planning, resource (material, machines and manpower) requirement planning, and all other associated divisions such as purchase, marketing, etc. All these functions will be done at the facility level. It will also cover the auxiliary functions that support the manufacturing in terms of power, water, HVAC, human resource, and all other logistics.

• Enterprise: All the different facilities under the same management will be covering at this level. They would have the business data processing at the enterprise level to get the synergies from the operation of multiple facilities that have unified function to work for the same management. The enterprise needs to develop innovation-based environmental programmes that have significant managerial implications. The policies for human resource management to provide a very high awareness of the environment and provide them with high levels of technical and management skills in employees so that they can apply them in their respective spheres of activities. An example is Eastman Kodak which provided their designers all the necessary expertise to develop products that have high percentage of recyclable components.

• Global: In the highest level, the enterprise has its all facilities along with their supply lines. Because of the involvement of a large number of outside agencies logistics becomes a major requirement. The logistics team [23] need to involve at a number of stages: "first, the involvement of the logistics team in the product development phase, since the feasibility of most "green" product innovations depends on the possibility of managing the physical flows of goods effectively; second the design of new physical flows of products. In this respect, it must be noted that the growing concern for recycling-based practices may lead the logistics team to co-operate with firms operating in other supply value chains which can recycle end-of-life materials and/or products."

5. Case studies – SM Examples

5.1 Machine tool chatter

Chatter in machine tools is a common phenomenon and research in the area has been going on for the last 50 years with the work started at Birmingham University, UK and then continued at many places [27 - 29]. The problem becomes far more critical with the current use of high speed machining. High speed machining is particularly has great applications in mould and die making because of its ability to reduce a number of die finishing operations thereby decreasing the process time and machining cost.

In high speed machining, the machine tool enters a realm of spindle speed where it is no longer possible to determine from intuition or experience just where the ideal cutting conditions are likely to be found. The dynamic characteristics of the machine tool, tooling, workpiece, and work holding system affects the machining performance. It is known from the stability theory that the stable depth of cut varies depending upon the spindle speed as shown in Fig 3 [30]. In the Fig 1, the shaded portion is unstable region while the white region is stable. This diagram is specific to a particular machine tool and cutting tool combination. This is based on the natural frequencies of the machine tool, work piece, work holder and the cutting tool used. Once this data is known it is possible to calculate this diagram and then select the stable depth of cut based on the available power at the spindle of the machine. When properly analyzed, it can be seen that it will have a variety of low-chatter zones occurring at different spindle speed values. Low-chatter depth of cut values will occur across the entire spindle speed range. If you change the tool in the same machine then the diagram need to be recomputed.

Since it is normally a cumbersome process the process engineers normally go for a safe depth of cut which is not affected by the spindle speed. It can be also seen in Fig. 3, the depth of cut for chatter free performance increases as the spindle speed increases. Therefore it becomes important for the process engineer to find these stable values. A company called BlueSwarf® (www.blueswarf.com) utilizes this methodology and developed an automatic system they call as a dashboard which will be customized for the individual machine tools. By properly inputting the required data for the cutting tool (done through a simple tap test to find the natural frequencies) will give the appropriate stable speeds as can be seen from the Fig. 4 [30] for the RPM dial. The green areas indicate the stable RPM values that also show the correct depth. They claim using this technology the companies can reduce the energy use for machining by as much as 79.5%.

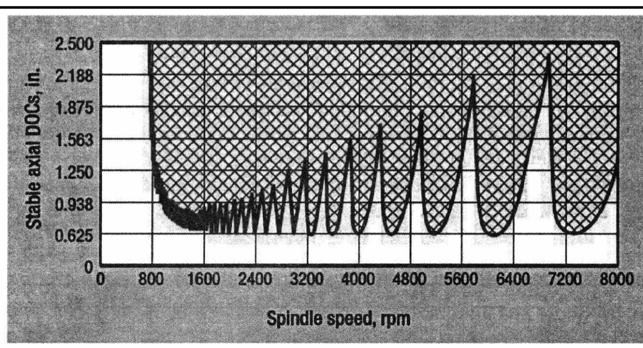

Fig. 3 Stability diagram developed utilizing the dynamics of the machine tool-workpiece-cutting tool system. Data required for this diagram is obtained from a tap test on the cutting tool used [30].

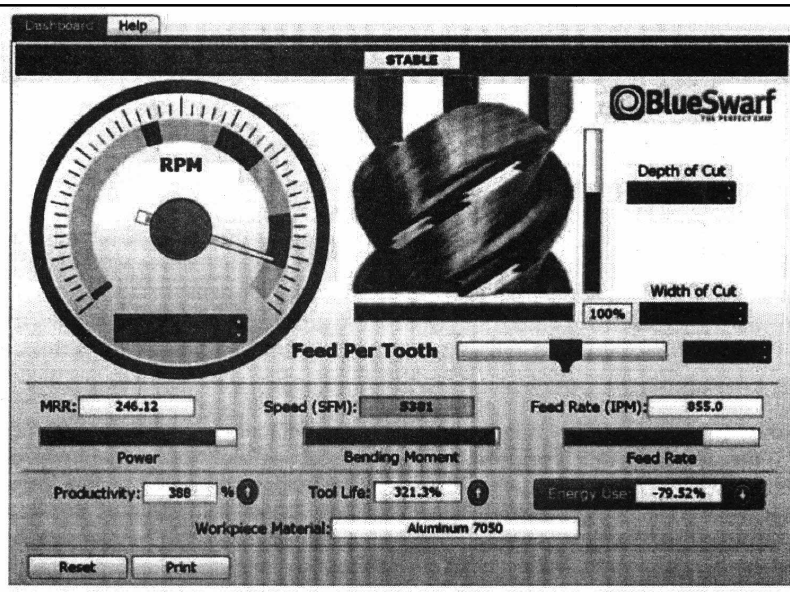

Fig. 4 Dashboard as seen from the software from Blue Swarf. The machine tool settings for stable cutting are obtained from here [30].

5.2 Cutting Fluids

Cutting fluids are used extensively in metal machining processes to remove and reduce the heat during the machining operations. The use of cutting fluids greatly enhances the machining quality while reducing the cost of machining by extending tool life. A large variety of cutting fluids based on organic and inorganic materials have been developed. However the large scale use of cutting fluids have a variety of environmental effects because of which modern production has been forced to pay greater attention to this aspect. The mist and vapor generated during the machining processes is harmful for the operator and stringent regulations exist to control them. Direct exposure of cutting fluids has been responsible for a number of skin cancer cases [31]. Stringent environmental legislations require that the spent cutting fluids be recycled or disposed of in a manner that is not harmful to the environment. This calls for increased expenditure on the recycling and disposal procedures used depending upon the type of cutting fluid.

It is reported by Klocke and Eisenblatter [32] that in Germany alone in 1994 it was estimated that 350,000 tonnes of cutting fluids were processed and subsequently disposed of. The cost of purchasing and disposing coolant is about one billion German Mark [33]. It is also estimated that cutting fluids cost 7-17 per cent of the manufacturing cost of components when associated costs of monitoring, maintenance, health precautions and absenteeism are taken into account in the German automotive industry compared to the tool costs that are quoted as being 2 - 4 per cent. As a result, increasing emphasis is now being placed on the research that can lead to the reduction in the costs associated with the cutting fluids by way of reducing the costs of their disposal or reducing the volume used.

It is reported [34] that in Japan the cost of purchasing coolant is about 29 billion Japanese Yen a year as per the Japan Lubricant Economy in 1984. The details of the cutting fluid consumption are as follows [34]: 100,000 kiloliter" water-immiscible (disposal cost 35-50 Yen per liter), 50,000 kiloliter water-soluble coolant without chlorine (disposal cost 300 Yen per liter), and 10,000 kiloliter water-soluble coolant with chlorine (disposal cost 2250 Yen per liter). Based on the above figures, the estimated coolant disposal cost alone in Japan is about 42 billion Yen. The total coolant purchasing and disposal cost is about 71 billion Yen a year [34].

Studies have shown that statistically significant increases in several types of cancer as well as an increased risk of respiratory irritation or illness are due to prolonged exposure to cutting fluid mists [46, 47]. Thus there is a need to reduce the usage of petroleum-based cutting fluids for manufacturing applications. The machining cost, environmental impact and operators' health concerns have driven researchers to find alternatives such as Minimum Quantity Lubrication (MQL) or equivalent dry cutting conditions that could satisfy the machining requirements without the use of cutting fluids [37, 38]. In MQL [41] the fluid used is generally straight oil, but some applications have also utilized water soluble fluids. These fluids are fed to the tool and/ or machining point in tiny quantities. The so called airless systems entails that a pump supplies " the tool with oil in a rapid succession of precision-metered droplets. This could also be done using air. When air is combined with the lubricant it becomes atomized in the nozzle to form extremely fine droplets which is termed mist application. However they concluded that machining at wet conditions was still better for tool life and dry cutting could only be of limited use at small depth of cut.

Alternative cutting fluids based on vegetable oils are bio-degradable as well as renewable [35 - 44]. Due to the relatively low flash point[1] (about 215°C), when petroleum-based cutting fluids are used, the heat at the workpiece-cutter interface often generates a mist, which is harmful to machine operators. Having a high molecular weight and high flash point of around 315°C, the soybean-based cutting fluids greatly reduce the chance of mist generation in machining processes. In addition, these soy-based cutting fluids have a very high film strength, which helps to lubricate the cutting tool-work piece interface thereby reducing heat and tool wear [42]. Though the bib-based cutting fluids have been available in the market for some time, their widespread use in industries is not prevalent. A limited number of studies on the bio-based cutting fluids have been reported in the literature [35, 36, 39, 42 - 45]. The research conducted by Belluco and DeChiffre's research [35, 36] specifically focused on the performance of formulated oils blended with rapeseed oil, ester oil and sulfur and phosphor additives used in drilling AISI 316L austenitic stainless steel. The experimental data indicated that the bio-based fluids performed better than the mineral oil-based products in drilling in terms of prolonged tool life, better chip breaking, lower tool wear and lower cutting forces. Similarly the work reported by Rao et al [43,44] indicate that use of soy bean based cutting fluids have advantages in terms of performance improvement comparable or better than the petroleum based fluids. This will improve its main credentials as green cutting fluid since it does not have any harmful additives that complicate the disposal procedures and hence the disposal cost.

[1]Flash point is the lowest temperature at which a liquid can form an ignitable mixture in air near the surface of the liquid. The lower the flash point, the easier it is to ignite the material.

Generally the objective factors considered in machining decision-making problems to select the cutting fluid are usually quality (Q), and cost (C). However they have added environmental impact (E) for considering the GM. Tan et al [49] proposed a multi-object decision-making model of cutting fluid selection for GM in which the objects of quality (Q), cost (C) and environmental impact (E) are considered together. The environmental impact (E) is based on

(i) Ecological impact: Machining processes have a harmful impact on the environment, due to the use of cutting fluid during the machining process. The main problem cost is the strict disposal guidelines for the waste-oil and waste-water from the cutting fluid.

(ii) Impact of occupational health and safety, and sanitation management: Use of cutting fluid will be detrimental in three ways to health of the operator and people around the machine shop: the toxic nature of the additives, the second is that the degreasing action of mineral oil harms the skin and finally the mineral-oil mist affects the lungs and breathing.

(iii) Problems: During the machining process, many operations cause problems. Many kinds of additives in cutting fluid would bring cauterization, rusting and fire disaster.

A case study on a decision-making problem of cutting fluid selection in the hobbing process of a gear was analysed which showed that the model is practical.

5.3 Foundry

Foundries traditionally recycling the used metal in the various forms as scrap to combine with the virgin metal thereby saving on the virgin metal requirement. They also recycle a large amount of foundry sand as high volume of sand (100 million tons) is used by the foundries. They routinely recycle most of the sand 'used. What the foundries have to do with the sand to reuse depends upon the process used for the mould and core making. In order for the sand to be reused after proper reconditioning, it has to pass through a number of sand tests such as AFS grain fineness number, green strength, moisture content, permeability, compactability, hardness and other physical and mechanical tests. The sand that passes through all these test will be used as regular moulding or core sand. However, after a number of reuses of the sand, it will not be possible to use sand for moulding purpose. Then it will be called as spent sand and is used for purposes other than casting. Some of the areas in which spent sand has been marketed include:

• Construction fill, road sub-base, and asphalt
• Flowable fill, grouts/ mortars
• Cement manufacturing and precast concrete products
• Potting and specialty soils

• Highway barriers, cemetery vaults, and bricks

• Landfill daily cover

Making castings from recycled metal products saves energy and conserves resources

• It requires 95%less energy to make castings out of recycled materials

• It reduces the energy demands for mining, refining, and many other metal-related processes

Recycling also reduces pollution risks by keeping materials out of disposal facilities

• Recycling steel (rather than using iron ore) reduces air pollution by 86%, water used by 40%, water pollution by 97%, and mining wastes by 97% (EPA)

• Waterman Industries (California) has for the last 10 years eliminated all landfill costs

• Kohler Co. (Wisconsin) has used 25,000 tons of foundry sand as construction fill

• Ford Motor (Cleveland casting plant) reuses 100% of spent sand in environmentally responsible projects.

Foundries world over face a problem with the emission of significant amounts of gases that are likely to be harmful to the environment. To that extent foundries and supplier industries are working at finding the methods that will improve the process while reducing the greenhouse gas emissions significantly. Moulding sand and core sands utilize significant amounts of binders to provide the necessary green and dry strength to the mould and cores. Depending upon the technology used these processes are named as Hot box process or cold box process. In hot box or heat activated processes the sand and binder after forming into shape is either baked or heated depending upon the process such as core sand with oils or shell moulding. In the coldbox process, foundry sand is mixed with liquid binder and cured by a vapor or gas catalyst that is passed through the sand at the ambient temperature. Several different coldbox systems are currently used, employing various binders and gases as catalysts. The use of cold box technologies greatly reduce the energy requirement for the process, but the use of chemicals are a case in question that need to be monitored properly for environment.

The traditional binders used by the foundries such as phenolic urethane faces a number of problems such as fumes, odour, pollutants and condensates. Inotec [50] inorganic binders for light-alloy and non-ferrous metal casting [51] eliminates 98%of emission while promising improvement in productivity. The component strength improved with higher productivity because of the simplified procedures. There is condensation giving rise to less porosity in the castings. No odours or fumes so that there is less need for treating foundry air.

University of Northern Iowa has developed bio- urethane [51] to replace the part 1 of the phenolic urethane used as sand binder. UNI's bio-urethanes serve as a direct replacement of phenolic urethane. The binders employ an isocyanate resin (part 2) and an amine catalyst very similar to phenolic urethane no bake and cold box binders, so that no change in the current foundry equipment used. That helps in utilizing bio-urethane with the existing foundry operations with ease. Testing has shown that the UNI bio-urethane binders exhibit less core distortion than conventional phenolic urethane binders. There are several advantages environmentally to use these binders:

• Reduction in the use of petrocherntcats

• The foundry atmosphere has fewer odors during mold and core making.

• When compared to a traditional phenolic urethane no-bake, both blo-urethanes generate over 50% reductions in overall emissions of HAPs during pouring, cooling, and shakeout.

6. Research Directions

As discussed above, there are many directions in which the engineers will be able to attempt to reach green or sustainable manufacturing. The research directions for green manufacturing therefore can be broadly classified into the major areas that are similar to the manufacturing enterprise as

• Product Design for Sustainability

• Sustainable Manufacturing Processes

• Sustainable Manufacturing Systems

6.1 Product Design for Sustainability

Traditional product design procedures costs approximately 5 - 7% of the entire product cost, while the decisions made during the early stage of design lock in 70-80% of the total product cost [52]. We can also hypothesize that based on the early decisions made affects to a great extent the sustainability of the product. It is therefore necessary for the designers to utilize special tools to assess the environmental impact in view of the limited availability of information in early stage of design process.

As detailed earlier, LCA has been considered as a tool for establishing the product sustainability throughout its life. Embedding the environmental considerations into product and process engineering design procedures is called as Design for environment (DFE). It is used to develop environmentally compatible products and processes while maintaining product, price, performance, and quality standards. For this purpose a number of design tools are already available, ISO-TR 14062 [14] suggests the availability of some 30 tools for this purpose. Since then a number of other design tools have also become available. Most of them utilize check lists [53], Quality function deployment (QFD) [54, 55] or based on LCA [56 -59]. A sample check list suggested is given below [53]:

ONE Do not use toxic substances and utilize closed loops for necessary but toxic ones.

TWO Minimize energy and resource consumption in the production phase and transport through improved housekeeping.

THREE Use structural features and high quality materials to minimize weight in products. If such choices do not interfere with necessary flexibility, impact strength or other functional priorities.

FOUR Minimize energy and resource consumption in the usage phase, especially for products with the most significant aspects in the usage phase.

FIVE Promote repair and upgrading, especially for system-dependent products. (e.g. cell phones, computers and CD players).

SIX Promote long life, especially for products with significant environmental aspects outside of the usage phase.

SEVEN Invest in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear, thereby ensuring reduced maintenance and longer product life.

EIGHT Prearrange upgrading, repair and recycling through access ability, labelling, modules, breaking points and manuals.

NINE Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and no alloys.

TEN Use as few joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking, etc. according to the life cycle scenario.

The advantage with the checklists is that they are easy to use and very convenient at the early stage of the design process. However they are very subjective based on the designer's understanding and inclination. Proper use of these tools requires extensive experience and knowledge. As a result there will not be consistency between different designers as to the outcome of the application of these checklists.

QFD is traditionally used to convert customers' needs into engineering specifications [52] utilizing the benchmarking of the competitor's product characteristics. The modification to QFD is done by introducing the environmental impacts of the product itself and over its life cycle as new customer needs it is possible to develop a set of Eco design tools [54].ln the QFD for the environment (QFDE) [54], the voice of the customer for environment is specified in the form of less material usage, easy to transport and retain, easy to process and assemble, less energy consumption, etc. To get the engineering specifications for the environment are suggested such as weight, volume, number of parts, number of types of materials, likelihood of getting dirty, hardness, physical lifetime, etc. A functional analysis is then performed to identify how quality characteristics are correlated with engineering characteristics (including structure or components) and hot spots from both environmental as well as traditional quality points of view. One serious drawback of these QFD- based tools (similar to traditional QFD) is that the development of correlations between environmental needs and quality and engineering characteristics is totally on the designers, and usually the correlations developed are based on knowledge from the traditional environmental engineering discipline without the consideration of life cycle [31].

These include QFD for the environment, green quality function deployment, and House of Ecology [54]. In general, application of these tools starts from collecting both customer needs and environmental needs and developing correlations between these needs and quality characteristics. A functional analysis is then performed to identify how the environmental characteristics are correlated with engineering specifications (including structure or components) and thereby obtain sustainable engineering specifications from the environment point of view. The development of correlations between environmental needs and engineering specifications is totally on the designers, and usually the correlations developed are based on knowledge from the traditional environmental engineering discipline and may not consider the full life cycle [55].

As explained earlier LCA is the most common tool that is used for evaluating the environmental profile of a product or process [13, 15]. However the problem with LCA is that in order to conduct a LCA a lot of information is required, which makes it unsuitable for use in the early part of the design process. This is more difficult for a completely new design since no information from previous generation products will be available. Therefore efforts need to be put to see that simplified or streamlined LCA be developed for early part of the product design stage [58]. Another method tried is allocating environmental impacts across functions to assess the greenness of concepts generated during the early part of design [59]. Once the product concept is identified there are a number of computer aided tools that are available [56] that can be used to establish the environmental fidelity of the product design. Different analyses that can be carried out during the design stage using computer assistance are shown in Fig 5.

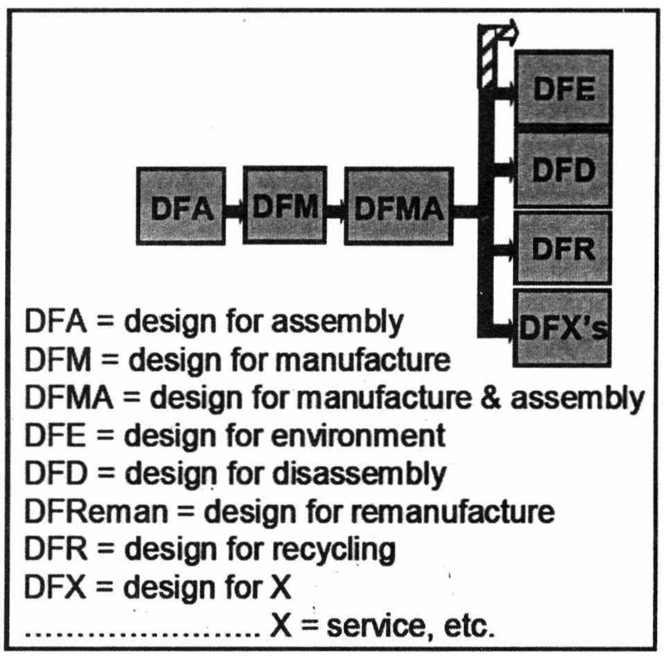

Fig. 5 Different product design methodologies [56]

Once the product design is completed in the 3DCADenvironment, it is possible to utilize specialized databases such as Simapro (http://www. pre-sustainability, com/simapro-Ica-software), GABI (http://www. Gabi software.com/ america/ overview /product-sustainability-performance/), and Ecoinvent (http://www.ecoinvent.org/home/), to provide a method to evaluate the total inventory and impact based on LCA and can generate the necessary reports. Similarly Solid Works Sustainability (http://www.solidworks.com/sustainability/sustainability·software.htm) provides actionable environmental results by measuring the environmental impacts of individual designs across the product life cycle, including the effects of material, manufacturing, assembly, and transportation based on standard databases. Similar products are available from other major CAD vendors as well.

6.2 Sustainable Manufacturing processes

The manufacturing process used to actually produce the product utilizes a large amount of resources and generates a large amount of emissions and waste that leads to environmental pollution in an enterprise [60]. To reduce the environmental impacts of manufacturing processes we need to organize into three categories: (1) optimize the environmental performance of the existing processes, (2) develop new green processes, and (3) green process planning.

6.2.1 Optimize the environmental performance of the existing processes

So far manufacturing processes are generally designed for high performance and low cost with little attention paid to environmental issues. Most of the time optimization of a process is done with reference to minimizing the machining time or machining cost with no consideration for the environment. The costing models considered rarely included the cost of environmental compliance. However it is necessary to consider the cost of compliance to the environmental guidance.

Hubbardet al [61] have proposed a cutting fluid cost estimation model to take care of the environmental requirements. They have utilized the following costs as part of the total machining cost. The total cutting fluid cost includes the following:

• Cost of purchasing the cutting fluid including the cost of recharging
• Cost of maintaining the cutting fluid, cost of additives along with the associated labor cost
• Cost of makeup fluid, the cost associated with the volumetric loss of cutting fluid due to evaporation, leakage, etc.
• Cost of pump out of the used cutting fluid
• Cost of system cleaning, i.e. flushing the system after disposing of the spent cutting fluid

They have found that this model adequately provides for the environmental cost.

A systematic method to assess energy consumption of machine tools for comparable analysis of data and to accurately evaluate the energy efficiency of various machine tools is necessary with increasing interests in green manufacturing. Vijayaraghavan and Dornfeld [62] introduced a framework to analyze the energy consumption and operational data of machine tools and other manufacturing equipment based on based on event stream processing. This capability simplifies environmental analysis and optimization for complex manufacturing systems, where decision making is required across multiple levels of abstraction.

Cao et al [63] developed a carbon efficiency approach to quantitatively characterize the life-cycle carbon emissions of machine tools. They defined carbon efficiency as the ratio of capacity or service value provided by machine tool to the corresponding carbon emissions. Since the carbon emissions closely relate to production rate, material removal, operation time and throughput, they can be reduced by improving energy efficiency and making the best matching of equipment and production tasks.

Since energy consumption reduction is critical machine tool manufacturers have been developing advanced functions for machines to monitor the power. Mori et al [64] measured the power consumption of machining center in various conditions. Based on the conclusion that modifying cutting conditions reduces energy consumption developed a new acceleration control. This new control method reduces energy consumption by synchronizing spindle acceleration with feed system.

Behrendt et al [65] proposed a coherent methodology by presenting a detailed description of different test procedures based on standardized workpieces. Applying this methodology they studied the energy consumption characteristics of nine machining centers. They potential benefits of the ability of energy Labelling the machine tool with the obtained data are discussed.

It is also possible to improve the efficiency of operating the machine tools by modifying the software. For example in deep hole drilling when programmed with peck cycle, the tool is withdrawn at programmed intervals to clean the chips. This may not be efficient use of energy. It is possible in deep hole drilling; the power consumption can be reduced with an adaptive pecking cycle, which executes pecking as needed by sensing cutting load. Also, synchronization of the spindle acceleration/deceleration with the feed system during a rapid traverse stage can reduce the energy consumption up to 10%. Similar results were presented for drilling processes by Neugebauer et al. [66].

Kara and Li [67] present an empirical model to characterize the relationship between energy consumption and process variables for material removal processes. This would be useful to optimize process parameters from the energy consumption view point. Diaz et al [68] presented a specific energy characterization model to predict the electrical energy consumed by a 3-axis milling machine tool during processing which is 97.4%for the part manufactured under varied material removal rate conditions.

Balogun et al [69] studied the effect that machine modules, auxiliary units and machine codes have on power and energy consumption during machining on the electrical current consumption. Based on the results, they developed a mathematical model for electrical energy use in machining and validated on a milling tool path. The paper also provides the impact of different machine modules, spindles, auxiliary units and motion states on the electrical energy demand budget for a machine tool resource. This helps in evaluating tool paths and re-designing machine tools to make them more energy efficient. Gutowski et al [70] tried to combine different manufacturing processes into a unified energy frame work. They observed that the total energy requirement is controlled more by the auxiliary equipment than the main process. So machine tools need to be redesigned taking this into account.

6.2.2 Develop new green processes

In addition to improving and optimizing the existing processes, it will also be important to develop new processes that use less harmful materials and generate fewer emissions which can then be considered as green processes. An example could be processes based on laser. Laser assisted manufacturing processes are likely to bring some environmental advantages by reducing emissions during manufacturing processes while extending the tool life because of its non-contact nature. However the energy consumption of laser processes is more compared to the conventional processes. Zhao et al [71] have conducted life cycle assessment to benchmark the environmental performance of two laser based processes to conventional processes, i.e. shot peening and turning. The results of this study show that the environmental performance of the two laser based processes is significantly better than conventional processes. A brief cost analysis conducted by them suggested that both these can be economically viable with payback period less than three years for niche applications.

Morrow et al [72] compared the energy consumption and emissions associated with the production of mold and die tooling via laser-based Direct Metal Deposition (DMD)and CNC milling. They showed that simple molds with high solid-to-cavity volume ratio and minimal amounts of finish machining are least environmentally burdensome to produce via CNC milling, while molds with a low solid-to-cavity volume ratio are least environmentally burdensome to produce via DMD.

It is known that the selection of process parameters can have a significant influence on the consumed energy and resources. Reducing energy consumption in a machine tool can be done by recovering the energy through the use of a kinetic energy recovery system (KERS) similar to regenerative breaks used in automobiles. Diaz et at. [73] have found that 5 to 25%of energy saving can be achieved by having a KERS device on the 'machine tool based on simulated conditions. They also illustrated that the energy consumption for drilling and face/end milling can be reduced by setting the cutting conditions (cutting speed, feed rate and cutting depth) high, thereby shortening the machining time, yet within a value range which does not compromise tool life and surface finish.

6.2.3 Green Process Planning

Another important area of research is the application of green principles in process planning as it bridges the design and manufacturing. However to date not much is published in this area. The manufacturing plan outlines the selection of the manufacturing processes, sequencing of the processes, and parameters for each manufacturing process. Process planning systems mostly concentrate on optimizing the production efficiency, cost, and product quality. They also utilize a large amount of data such as established standards, machinability data, machine capabilities, tooling inventories, stock availability, etc. There is a large amount of research in the computer aided process planning methodologies, but sustainability is rarely considered as a requirement.

Srinivasan and Sheng [74, 75] developed a framework to include the environmental impact for process planning. They included in their analysis the production rate, quality, process energy and mass of waste streams generated by the process. While there has been a body of work developed in life cycle analysis, one of the critical issues limiting environmental analyses is the material and geometric complexity of engineered components. They provided a formalized approach towards integrating environmental factors in process planning that incrementally evaluates part designs through an aggregation of features. In their approach process planning is divided into two phases, micro and macro planning. In micro planning, process, parameters, tooling and cutting fluids are selected for the individual features, while in macro planning interactions between features are examined.

7 Conclusions

Sustainable manufacturing is the most important aspect to be considered by all production engineers, not because it is a fad but a necessity as an obligation to the world we live in. Product life cycle analysis has become a tool of choice being used to establish the environmental impact of the products that we produce. Though application of PLA is time and data intensive, provides very clear avenues where engineers will be able to reduce the environmental impact. There are a number of areas within manufacturing that can be benefited greatly by the adoption of green manufacturing practices. The researcher will have to start thinking from a different viewpoint than what they do now. Practically all areas of manufacturing are fertile to consider adoption of green manufacturing. The three major principles to be considered are reduce the resource utilization in the process, use environment friendly materials, reduce all forms of waste and reuse and recycle as much material as possible to realize the goal of self-recovery capability of earth Examples presented in this paper provide such examples for others to follow.

Machining Challenges: Macro to Micro Cutting

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Abstract

Metal cutting is an important machining operation is the manufacture of almost all engineering components. Cutting technology has undergone several changes with the development of machine tools and cutting tools to meet challenges posed by newer materials, complex shapes, product miniaturization and competitive environments. In this paper, challenges in macro and micro cutting are brought out. Conventional and micro end-milling are included as illustrative examples and details are presented along with discussion. Lengthy equations are avoided to the extent possible, as the emphasis is on the basic concepts.

Keywords: metal cutting, end milling, cutting forces, surface finish

1 Introduction

Machining is an important step in the manufacture of engineering components for different applications. Apart from consumer products sector, wide range of sectors involved in energy, automotive and space applications also use machining extensively in the manufacture of the various components. Since volume of material removed is smaller compared to the volume of manufactured component, machining is still considered to be the most economical operation. Attempts are made to manufacture Near Net Shape parts, but these components also require machining of functionally important surfaces to some extent. Material removal by shearing action is often referred to as metal cutting and it requires a cutting tool harder than the work-material. The most important property of the tool material is that the cutting ability must be retained even at higher temperatures as encountered in the metal cutting. The cutting elements are arranged on the cutter body according to the type of operation, namely turning, drilling, shaping, broaching, milling, etc. The abrasive grains act as cutting elements in grinding operations. Fig. 1 shows typical metal cutting operations.

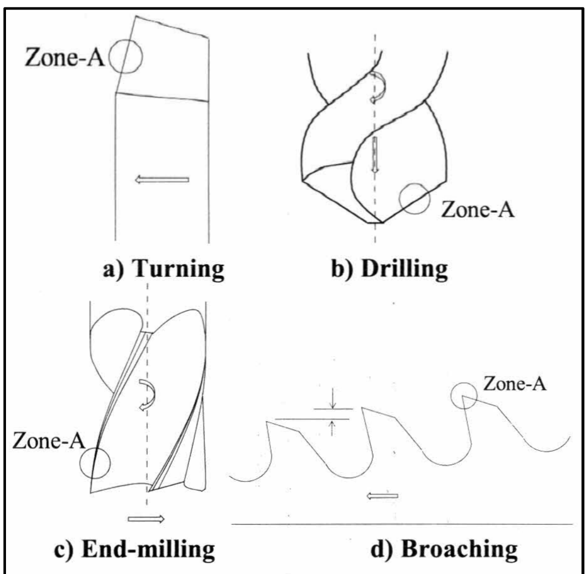

Fig. 1 Typical metal cutting operations (Zone-A: cutting element)

Broaching being one-pass operation, the width of cut and depth of cut for roughing, semi-finishing and finishing are incorporated in the tool itself. In single stage drilling, the drill size determines the width of cut and hence feed and cutting speed are the only variables. In many operations like shaping, turning, milling, grinding, etc., the values of depth of cut, feed, cutting speed are chosen depending on need for rough and finishing passes. Since the cutting tools are in direct mechanical contact with the workpiece, a good geometric correlation between the tool path and the machined surface is ensured. It is interesting to note that the earlier practitioners/researchers had a limit of 0.05 mm for the depth of cut in their mind, and most of the machining trials were carried out with depth of cut of 0.05 mm and above. The tool/table setting was also done through a precision screw with 0.05 mm graduated dial. Introduction of CNC has led to automation of tool-change and tool-path movement, thereby improving the productivity and maintaining consistency of product quality. Cutting-tool technology also matches the productivity and quality requirements using different cutting tool materials and coating techniques. Now the conventional metal cutting technology has reached such a maturity level that complex three-dimensional geometries practically in all materials can be produced.

Recently the need for high precision miniaturized components has also increased across various industry sectors. The barrier of 0.05 mm on depth of cut has vanished and it has become possible to go below 0.05 mm with high-precision and high rigidity machine tools. Micro-cutting has become an important process in the manufacture of miniaturized components. Due to direct mechanical contact between the tool and workpiece, machining of three-dimensional features with high aspect ratios and complex geometries has become feasible. Micro-cutting can be considered as a downscaled form of conventional cutting process and it involves use of tools with diameters in the sub millimeter range (equal to or less than 500 μm) or machining of features sizes in the same range. In micro-cutting, higher material removal rates, better accuracy and surface finish can also be achieved in comparison with other micro-machining processes.

When the practitioners face any problems with the conventional macro-cutting process, they often approach the cutting tool manufacturers for their guidance. For many academic researchers, this has opened up a wide variety of research opportunities. Lot of published work dealing with the conventional macro-cutting processes is available in the literature. The approaches followed by the researchers vary from simple experimental investigations resulting in empirical models to more fundamental investigations leading to mechanistic/analytical models. However, the domain knowledge available from the conventional macro-cutting process cannot be applied to micro-cutting in a straightforward way. Behavior of the material at micro scales is different and the cutting mechanics also requires appropriate modification as the tool edge can never be considered sharp in micro cutting. Therefore, investigation into micro-cutting processes has also emerged as an exciting area of research.

In this paper, macro-cutting is covered first, followed by micro-cutting operations. Since the boundary between macro and micro cutting is not very distinct, literature survey is presented taking a liberal view of the overlapping domain. In metal cutting research, various aspects such as tool geometry, characteristics of tool and work materials, chip morphology, cutting forces, surface finish, cutting temperature, tool wear and tool life are considered. In this paper, the literature survey is restricted to three major aspects, namely geometry, cutting forces and surface finish, in general and end milling in particular. As the major objective of this paper is to emphasis the basic concepts, lengthy equations and derivation are avoided to the extent possible. Typical machining research work carried out by the author and his group is presented in detail and discussed further, taking conventional (macro) and micro end-milling as examples.

2 Macro-Cutting

Earlier practitioners and researchers in metal cutting believed that a cutting tool would not be sharp and hence the uncut chip thickness had to be greater than the radius of the cutting edge. Generally, the edge radius on the cutting tool was found to be in the range of 0.02 - 0.05 mm. In earlier metal cutting experiments, uncut chip thickness of 0.1 mm and above was used (Merchant, 1945; Oxley, 1963). This also formed the basis for the selection of minimum feed/depth of cut in single point turning as well as multi point machining. In case of multi-point machining operations, the dimension of the tools such as drills, end mills and others, was generally taken to be 3 mm or above for macro cutting.

2.1 Review of literature on macro-cutting

The published literature on macro-cutting spans over seven decades and, therefore, only selected papers in macro cutting are included and reviewed in the following section.

2.1.1 Orthogonal cutting

All practical machining operations are 3-dimensional in nature, with cutting edge oriented at an angle to the cutting velocity and forces acting on it in 3-directions. In order to study the cutting mechanics, the researchers have resorted to a simplified cutting operation in which cutting edge is perpendicular to the cutting velocity and tool edge is wider than the workpiece width. In such orthogonal cutting condition, the cutting forces are 2-dimensional in nature and they lie in a plane which contains the cutting velocity and remains perpendicular to the cutting edge. The orthogonal cutting offers greater flexibility in the analysis of cutting mechanics.

A number of researchers have performed orthogonal cutting experiments either in shaping or turning mode with a sharp tool wider than plate or tube thickness, as the case may be. The shaping mode is employed for low speed investigations, while turning mode allows investigations to be carried out at high speeds. The cutting is assumed to be uniform along the cutting edge and, therefore, condition of two-dimensional plane strain deformation process without side spreading of the material is applicable. A schematic representation of orthogonal cutting is shown in Fig. 2.

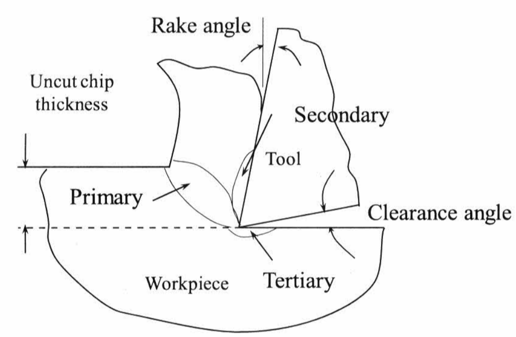

Fig. 2 Deformation zones in orthogonal cutting

Fig. 2 shows different deformation zones in the orthogonal cutting, namely primary zone of deformation in the material ahead of the tool, secondary deformation occurring in contact zone between chip and tool rake face, and tertiary deformation zone in the material below the tool tip. Primary deformation zone: Merchant (1945) analyzed the primary zone of deformation in orthogonal cutting extensively (Fig. 2) and showed that a circle could be constructed to represent different components of forces. He made several assumptions including that the tool is sharp and the material shearing occurs along a plane, while proposing a relationship between shear, friction and rake angles, based on minimum energy principle. A number of researchers have followed his work on such thin-zone model. In an important paper, Shaw (2003) has reported different values for the constant in the Merchants' relation for shear, friction and rake angles, based on tool-work material combination. Oxley (1961) has proposed a different approach considering that the deformation occurs in a curved zone, rather than a plane, and analyzed the thick zone of deformation using slip-line theory. Oxley (1963) also approximated the deformation zone to be a paralle1- sided zone and presented an analysis for a material having variable flow stress property. Analysis of the thick zone model has been continued by a number of researchers. Subsequently, Tounsi et al. (2002) have considered the deformation zone as a parallel-sided zone and derived the relations for velocity, strain and strain rates along a plane within the zone identified as a main shear plane. In an attempt to understand the effect of an edge-radiused tool, Manjunathaiah and Endres (2000) have developed an analytical model on the basis of thick deformation zone developed with an edge-radiused tool. An investigation into roundededge tool has been carried out using slip-line modeling in which the shear zone thickness has been derived taking a parallel-sided shear zone as a special case (Fang, 2003a, 2003b).

Secondary deformation zone: Deformation occurring at the tool-chip interface (Fig. 2) in macro cutting has been investigated with great interest by a number of researchers. In Merchant's model, the chip-tool frictional behaviour has been represented by a single value of the mean coefficient of friction on the tool rake face. In later studies, direct and indirect observations of the chip-tool interface region by many investigators have led to the conclusion that the chiptool interface consists of sticking region closer to the cutting edge wherein the material flow occurs by shear within the chip. Following the sticking region is the sliding region, in which the chip slides over the rake face of the tool till it leaves the contact with the tool. Contact conditions at the rake face of the tool have been investigated by a group of researchers (Ackroyd et al., 2001). Ozlu et al. (2009) have derived the expressions for evaluating overall mean friction considering the sticking and sliding friction at the tool-chip interface. The advantage claimed by them is that the derivations are independent of the nature of deformation at the tip.

Tertiary deformation zone: Deformation zone below the tool-tip has also been investigated extensively. Both tool having non-sharp cutting edge and sharp tool with built up edge formed are assumed to have same effect on the tertiary deformation zone (Fig. 2). In order to simulate the above conditions, researchers have used a radiused or blunt-tip tool. Due to radius effect, effective rake angle changes from its nominal value and becomes more negative.

An expression for the change of rake angle with uncut chip thickness and tip radius can be derived geometrically. In an independent work, Komandurai (1971) has shown that cutting is possible with high negative rake and reported a limiting angle of -75 to - 76°. Apart from change of the effective rake angle, the material flow separates from cutting to ploughing at certain point on the radiused portion of the tool. This point is referred to as a stagnation or neutral point, below which the tool ploughs through the material instead of cutting thereby creating an additional force. Abdelmoneim and Scrutton (1974) have arrived at the expressions for the ploughing force components for a given stagnation point angle using the analogy of a hard cylinder pressed against a flat surface. The results have been validated taking a stagnation point angle of 14°, a value that could be deduced from the limiting rake angle reported by Komanduri (1971). The ploughing component of the force in orthogonal cutting has been analyzed using slip-line field and compared with the experimental values (Waldorf et al., 1998). In a different attempt, researchers have attempted to show that edge radius modifies shear zone thereby modifying the cutting forces and hence there is no need to include a ploughing component (Schimmel et al., 2002). A good comparison of experimental methods for evaluating the ploughing force in orthogonal can be found in a paper published recently (Popov and Dugin, 2013).

The researchers, who continued to investigate the effect of uncut chip thickness, have reported different values for stagnation point angles. It may be noted that a relationship exists between minimum uncut chip thickness and the stagnation point angle. Minimum uncut chip thickness is defined as the thickness below which the chip formation does not occur and ploughing force dominates leading to plastic deformation of material. Basuray et al. (1977), based on a different theoretical analysis, predicted the stagnation point angle to be 37.6° and validated it through the orthogonal cutting experiments on mild steel, lead and aluminum. Manjunathaiah and Endres (2000) reported a value of 30° and effect of edge radius was further investigated by Kountanya and Endres (2001).

Mechanistic approach: Few attempts have been made to evaluate specific coefficients for cutting and ploughing through orthogonal cutting experiments. Armarego and Whitfield (1985) and Armerego and Deshpande (1989) have reported that the coefficients are evaluated through orthogonal cutting tests. Estimation of force coefficients through orthogonal cutting tests has also been done by Budak et al. (1996) and Altintas and Lee (1996). Though these coefficients are helpful in understanding of the influence of cutting conditions, they do not bring out the actual mechanics involved in cutting.

Size effect: Researchers in conventional metal cutting have observed that the specific energy in cutting increases asymptotically with reduction in uncut chip thickness. It is interesting to note that attempts have been directed towards the study of size effect in orthogonal cutting starting from 1950 (Shaw, 1950; Armarego and Brown, 1962; Nakayama and Tamura, 1968). Such studies have paved way for possible research into micro cutting considering size effect in the last decade.

2.1.2 Oblique cutting

The orthogonal cutting studies are extended to oblique cutting with a view to apply the oblique cutting results to practical machining operations such as turning, drilling, end-milling and others. A good treatment of oblique cutting can be found in the paper authored by Brown and Armarego (1964) as well in the book published by Armarego and Brown (1969). Other researchers have also carried out oblique cutting studies and reported their findings. Pal and Koenigsberger (1968) concluded that cutting forces are controlled mainly by normal rake angle and are independent of inclination angle in oblique cutting. Vinod et al. (1978) proposed a new oblique cutting model and suggested an equation for the chip flow angle in oblique cutting, considering shear and rake angles. Rubenstein (1983) proposed oblique cutting model considering absence of chip distortion and verified it with experimental data, while Fang (1998) proposed an improved model of oblique cutting and proposed new relations to precisely find effective rake angle and effective shear angle.

Similar to estimation of force coefficients in orthogonal cutting, corresponding coefficients for oblique cutting are estimated from the experiments carried out in turning mode (Budak et al., 1996). They have concluded from the experiments that the coefficients are not affected by obliquity.

2.1.3 Conventional (macro) end-milling

Researchers have studied the geometry of end milling cutter, cutting forces, vibration, surface finish, tool wear and many related aspects. In this section, only the literature covering geometry, cutting forces and surface finish in the macro end milling is presented.

Geometry of end-milling cutter: In a flat end milling cutter, end cutting edges are provided with proper rake and relief angles. The helical nature of the flute ensures smooth entry into the cutting zone. The peripheral cutting edge along the helix is also provided with relief in the radial direction to avoid rubbing with the generated surface. Generally, a suitable radius is provided at the comer which serves the same function as nose radius on a single point tool used in turning operation. End mills with throw-away inserts held in a holder are available for diameters 20 mm and above. Specific details can be found in the manufacturers' catalogues, as each manufacturer claims superior performance with certain geometrical and technological changes introduced. A good treatment of end mill geometry can be found in the book of Armarego and Brown (1969). The relation between the radial rake, normal rake and helix angles has been derived and reported in this book.

Cutting forces: For prediction of cutting forces in end milling, analytical as well as mechanistic approaches have been followed by the researchers. The forces acting on the cutting edge of end mill are analyzed and the relevant relations are given by Armarego and Brown (1969). The forces variations in end milling are modeled and reported by Tlusty and MacNeil (1975), Armarego and Deshpande (1989), Armarego (1998) and Altintas (2000). A threedimensional model of cutting forces in peripheral end milling was developed by Zheng et al. (1996), considering the material properties, cutting parameters, machining configuration, and tool/work geometry. A comprehensive model that simulates end milling processes in time domain under general cutting conditions has been developed by Li and Shin (2006). Jerard et al. (2006) have focused on developing geometric model for uncut geometry and mechanistic model for prediction of force and power. A cutting force model for end milling has been presented by Palanisamy et al. (2006) to predict the tangential cutting force and the thrust force. Budak and Ozlu (2008) have presented a thermo-mechanical model for cutting simulation and applied the same to milling process.

Kline et al. (1982) estimated the empirical constants directly from the average forces measured in end milling experiments and used them in the prediction of cutting forces. Kline and DeVor (1983) have proposed an improved mechanistic cutting force model for flat-end milling including the effect of cutter run-out and cutting system flexibility. The model required large number of cutting tests with different combinations of cutting conditions is to determine the average value of coefficients in the models. To reduce the number of cutting tests, Yucesan et al. (1993) represented the cutting pressure coefficients as a function of both rotation angle and the position of a cutting edge point. Armarego and Deshpande (1989) have developed models including the eccentricity and deflection effects and using mechanics of cutting to predict average and fluctuating force components in end milling. In subsequent work, Budak et al. (1996), Altintas and Lee (9996) and Gradisek et al. (2004) have demonstrated that the milling force coefficients could be determined from orthogonal cutting tests with oblique cutting analysis and transformation. Adetoro and Wen (2010) have employed arbitrary Lagrangian formulation in the finite element simulations to determine both average and instantaneous cutting force coefficients. For evaluation of specific cutting coefficients in the mechanistic model to predict forces in milling, an inverse method has been proposed by Gonzalo et al. (2010).

Zheng et al. (1996) proposed an explicit expression of cutting force waveforms in end milling with helical multi-flute cutters, as algebraic functions of tool geometry, machining parameters, cutting configuration and workpiece material properties. The closed-form nature of the resulting model facilitates force estimation and process optimization without resorting to numerical iterations. Wang and Zheng (2003) presented an analytical milling force model in the frequency domain that can provide the shearing and ploughing constants, in a linear closed-form equation, in terms of cutter geometry, cutting depths and the Fourier coefficients of the milling forces. Ekanayake and Mathew (2008) have proposed an analytical model extending the orthogonal cutting model and applying variable flow stress theory.

Statistical and artificial intelligence (AI) techniques have also been applied for modeling and prediction of the cutting forces in end milling. Fuh and Hwang (1997) have developed statistically a second order model for cutting force in end milling, in terms of cutting parameters such as speed, feed, axial depth of cut and radial depth of cut, using response surface methodology (RSM). Monitoring of forces reveals tool condition (Jemielniak, 1999; Haber et al. 2004). Among other AI techniques found in the literature, model developed by Kovacic et al. (2004) uses genetic programming to predict the cutting forces in milling, in terms of the material properties (tensile strength and hardness of work piece), type of milling parameters, tool diameter and type of milling. Torabi et aI., (2009) have presented a survey of AI techniques applied to high-speed end-milling.

Surface finish: Surface finish is influenced by the type of machining operation and the machining parameters used. Literature shows that a number of attempts have been made to study surface finish obtained in end-milling. The cutting conditions such as speed, feed/tooth and axial depth of cut as well as the process dynamics influence the surface finish in conventional end-milling. For a given corner radius on the end mill, the surface roughness on the side wall and bottom surfaces is influenced more by the feed when compared to other two cutting parameters. Ryu et al. (2006) analyzed the roughness and texture generation on end-milled surfaces. In order to produce high quality parts with greater savings in production time and production cost, proper selection of cutting parameters becomes essential. Some researchers have used statistical methods and AI techniques to predict the surface roughness in end-milling operations (Ozcelik and Bayramoglu, 2006; Zain, 2010). Saikumar and Shunmugam (2006) have modeled the surface finish obtained in high speed end-milling of AI-Cu alloy by RSM and applied differential evolution for the selection of cutting parameters. In another attempt, Taguchi optimization method has been used to optimize surface roughness value (Ra) in terms of cutting parameters in milling (Zhang et al., 2007). Optimal selection of the cutting parameters for surface finish in end milling has been achieved by integrating RSM with evolutionary algorithms by some other researchers (Prakasvudhisarn et al., 2009; Routara et al., 2009). These models for surface finish are developed from the experimental data obtained with fresh tools.

Since online measurement of surface finish is difficult, researchers have always tried to find process response which can be measured online and correlated with the surface finish. Dynamic analysis of end milling process has been extensively done by Mativenga and Hon (2005) who have shown that the cutting forces developed during the milling process can be directly or indirectly used to estimate process performance, including surface finish.

2.2 Investigations into macro end-milling

The literature survey on conventional cutting has revealed that cutting mechanics and related phenomena have been investigated exhaustively. The major challenges faced by the practitioners and researchers are improvement in productivity and enhancement of product quality, particularly when dealing with difficult to machine materials. Therefore high speed milling has emerged as an alternative process (Schmitz et al., 2001). In this section, high speed end-milling is taken as an example, as it exhibits tremendous potential to improve productivity and surface finish (Dewes and Aspinwall, 1997; Werthiem, 2002). The details included in this section primarily cover cutting forces, tool wear and control strategies for rough and finish end-milling of hardened EN 24 steel. While relevant information extracted from the research work of Saikumar is presented here, more details can be found from the papers published by Saikumar and Shunmugam (2011,2012).

2.2.1 End-milling experiments

The experiments have been conducted on a vertical 3-axis CNC Mikron high-speed milling machine, model VCP710 for rough and finish endmilling operations as shown schematically in Fig. 3. The machine is equipped with 15 kW spindle power and maximum speed and feed rate of the machine are 12,000 rpm and 20 m/min respectively. End-mill holder of Φ10 mm (HM90 E90A-IO) and TiAIN coated P30 grade inserts (HM90 APKT 1003 PDR) of ISCAR make are used. The end-mill holder with a single insert is used and a tool overhang of 40 mm is maintained for all the experiments to minimize the effect of setting error and run out (Saikumar, 2011).

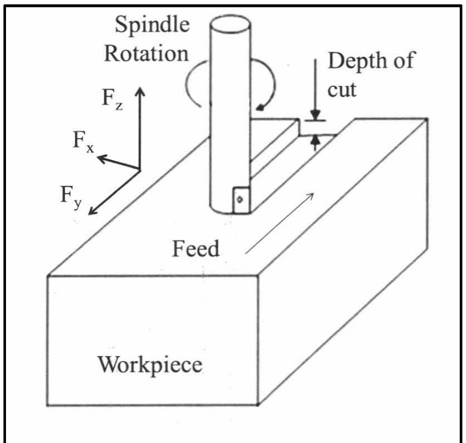

Fig. 3 Schematic of end-milling operation

The cutting forces are measured using 3-component Kistler dynamometer (Model 9265B) and charge amplifier (Model 5011). Data Acquisition is performed with a personal computer and a multi channel data acquisition board (PCIM-DAS1602), at a sampling frequency of 30 kHz. For flank wear measurement, a special vice is used to position the insert. The flank wear is measured at 20-magnification with 1 μm least count as per the recommendations of ISO 8688-2 using an optical measuring machine, Flash make Model 200 Switzerland. The surface roughness Ra is measured using Mitutoyo roughness measuring instrument in the initial portion of the slot. A cut-off of 0.8 mm and a tracing length of 2.5 mm are used and an average of nine readings is taken to represent the surface roughness.

The work material is EN24 (AISI 4340) steel. The test specimens of size 155×185×35 mm are hardened in vacuum furnace and tempered to achieve uniform hardness of 43-45 HRc. Based on central composite design, 16 combinations of parameters are identified for carrying out the experiments (Montgomery, 2000) in roughing and finishing modes. In each experiment, a new insert is used. Slots of 185 mm length are machined and several cuts are needed to observe the progression of flank wear (VB) up to the desired value.

2.2.2 Rough End-milling

In rough end-milling operation, the given tool is expected to remove as much as material as possible. Apart from the machining parameters such as spindle speed, feed and depth of cut which are independent/controllable factors, the progression of flank wear on the insert also influences the volume of material removed. Faster wear out of the insert can adversely affect the volume of material removed. Parameter Selection: From the experimental data, the response surface for volume of material removed (MR) is obtained in terms of spindle speed (n, rpm), feed (s, mm/min), depth of cut (a, mm) and flank wear (VB, mm) as given below:

$$MR = f_m\ (n, s, a, VB) \quad (1)$$

Even though VB is a dependent variable, it is introduced in the above equation to reflect the deterioration in cutting ability. Care is also taken to pickup MR values, when VB is closer to 0.1, 0.2, 0.3 and 0.4 mm. Such response surface is useful for prediction as well as control purposes. A second degree polynomial is fitted ($R^2 = 0.8905$) using Statistic a 6.0 (Saikumar and Shunmugam, 2012). In the work reported, a new objective function is proposed to select the machining parameters to achieve material removal within a specified range of values.

$$Obj = |Y - Y_{min}| + |Y_{max} - Y| \quad (2)$$

where Y_{min} and Y_{max} are the minimum and maximum MR values specified and Y is given by Eqn.l. It can be seen that minimum value of objective function will be the range itself, i.e. $|Y_{max} - Y_{min}|$. Differential Evolution (DE) algorithm proposed by Storn and Price (1997) is employed for the minimization task and DE code available in Matlab 7.1 is used. The algorithm is run several times, and results obtained for one typical range of volume of material values are recorded. Taking a range of 80-100(10^3) mm^3 for MR, different combinations of speed, feed, and depth of cut are obtained for VB lying between 0.38 and 0.4 mm (Saikumar and Shunmugam, 2012). One such combination of speed (n): 4707 rpm, feed (s): 230 mm/min and depth of cut (a): 2.490 mm for VB = 0.388 mm gives MR of 99.664 (10^3) mm^3.

ANN model for control parameters: Cutting force being the most sensitive to tool wear, the first task is to determine the cutting force component which correlates well with the progression of flank wear. A part of signal data consisting of 3 cycles is considered for the processing of cutting force signals in X; Y and Z directions, namely transverse (F_X), feed (F_Y) and axial (F_Z) forces. The tooth passing frequency for the maximum cutting speed of 11,681 rpm with a single insert is found to be around 200 Hz. Therefore, cutting force signals are filtered using a low pass filter having a frequency cut-off of 200 Hz. Gaussian filter is selected in the present work, as it is an averaging filter, which has zero phase-shift and distortions. It removes high frequency components and provides smoother signals for further interpretation. Matlab code is developed for Gaussian filtering (Matlab, 2005) and the filtered signal is designated as F_{Xg}, F_{Yg} and F_{Zg}. The filtered signal is subtracted from the original signal and they are designated as F_X-F_{Xg}, F_Y -F_{Yg} and F_Z-F_{Zg}. Fig. 4 shows amplitudes of the signals taking F_Y -F_{Yg} and F_Y -F_{Yg} as examples.

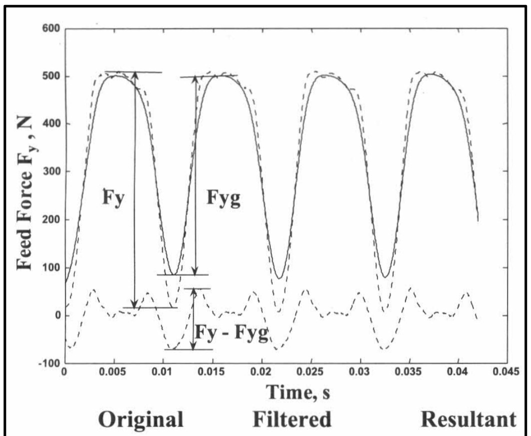

Fig. 4 Feed force (F_Y) signals for a typical combination of rough end-milling parameters

In order to identify the cutting force component among F_X, F_Y, F_Z, F_{Xg}, F_{Yg}, F_{Zg}, F_X-F_{Xg}, F_Y-F_{Yg} and F_Z-F_{Zg} which correlates well with the tool wear, 2nd order polynomial function is fitted taking cutting parameters and the tool wear as input parameters and each component of cutting force as output parameter. It is seen that F_{Yg} yields the highest R^2 value of 0.9484, and, therefore, the values of F_{Yg} are used for further processing.

For on-line control of rough end milling operation, it becomes necessary to monitor the cutting force and cutting time. Whenever the actual cutting force or the cutting time exceeds the reference values, appropriate control must be brought in. In the present work, ANN is developed to predict the cutting force and cutting time, given the input variables such as cutting speed, feed, depth and flank wear. A single ANN model with Bayesian regularization is used to predict reference cutting force and cutting time simultaneously (MacKay, 1992). Matlab's neural network toolbox (Matlab, 2005) is used to train neural networks taking the experimental values of cutting force component F_{Yg} and cutting time Ct for different values of speed (n), feed (s), depth of cut (a) and flank wear (VB). The parameters are normalized to lie between 0 and 1, by fixing the minimum and maximum values. The final network structure of 4-9-10-2 is also tested using additional data set. The weights and biases are stored for further use (Saikumar and Shunmugam, 2011). For the set of cutting parameters identified by DE, the reference cutting force and cutting time are obtained as $F_{Yg(REF)}$ = 962 N and $Ct_{(REF)}$ = 19.265 min with the developed ANN.

2.2.3 Finish End-milling

In finish milling, the cutting insert is replaced when it fails to produce the required surface finish. As the surface finish is affected by the tool-wear, tool wear is also taken to be an influencing factor.

Parameter Selection: Using the experimental results of finish end milling, surface roughness is expressed as

$$Ra = f_s\,(n, s. a. VB) \quad (3)$$

The 2nd order best fit polynomial equation for surface roughness gives a regression coefficient (R^2 Value) of 0.8028, where spindle speed (n) is in rpm, feed (s) is in mm/min, depth of cut (a) is in mm and flank wear (VB) is in mm.

The methodology applied for selection of cutting parameters for rough end milling process has been implemented for finish end milling also. In this case, three factors such as cutting speed, feed and depth of cut, are used to predict surface roughness for finish end milling process with flank wear lying between the specified values. Since flank wear for rough end milling is taken to lie between 0.38 and 0.4 mm, the corresponding values for finish end-milling are taken as 0.28 and 0.30 mm. For a given range of 0.15-0.20 urn Ra values, the results of DE are obtained. A typical combination of parameters identified by DE, namely speed (n): 11655 rpm, feed (s): 370 mm/min and depth of cut (a): 0.430 mm for VB = 0.281 mm gives Ra of 0.163 urn,

ANN model for control parameters: In case of finish end-milling, the cutting force component more sensitive to flank wear is identified from the correlation coefficients between flank wear and various components of cutting forces. In the present case, F_X-F_{Xg} shows a better correlation (R^2 value) of 0.8961 and the dynamic component is the difference between F_X (maximum cutting force before filtering) and F_{Xg} (maximum cutting force component after Gaussian filtering).

A network of 4-4-7-1 obtained for prediction of reference force component $F_X - F_{Xg}$ has been tested for its performance using additional data set. The weights and biases are stored for further use. For the set of cutting parameters identified by DE, the reference component $(F_X - F_{Xg})$ REF obtained using the developed ANN is 272 N.

2.2.4 Implementation of control strategies

A PC based control system has been configured using NI hardware and Lab VIEW software. A test part as shown in Fig. 5 has been prepared. When the end-milling proceeds from left to right, the cutter encounters a hard portion followed by air and a soft portion followed by again a hard portion. Hence this test part is referred to as H-A-S-H part. Two strategies shown in Fig. 6(a) and Fig. 6(b) have been selected for rough and finish end-milling respectively. Taking the parameters predicted by ANN for rough end milling, feed of 230 mm/min is taken to be 100% for a spindle speed of 4707 rpm and a depth of cut of 2.49 mm. The reference F_{Yg} is 962 N and the value of 512 N for VB=0.1 mm is taken to be lower limit. In case of finish end milling, feed of 370 mm/min is taken to be 100% for a spindle speed of 11655 rpm and a depth of cut of 0.43 mm and reference F_X-F_{Xg} is 272 N. During initial trials, a lower limit of 25% (68 N) is found to give the desired surface finish results. The feed variations shown in Fig. 6 are programmed using Lab VIEW for control purposes.

The trials on H-A-S-H test parts show nearly 14% reduction in cutting time, as the cutter moves faster during air-cuts. In addition, long run tests (155×185×35 mm hardened EN24) were also conducted in CNC mode using the cutting parameters predicted by ANN as well as using PC based control system. The control strategies implemented have led to improved performance in both roughing and finishing operations.

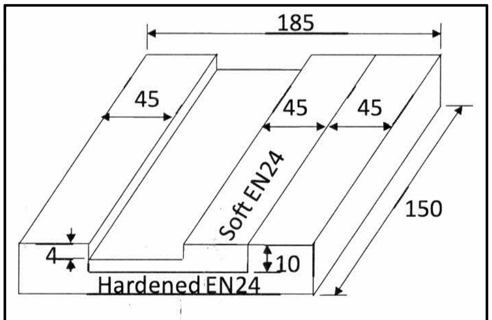

Fig. 5 H-A-S-H Test Part

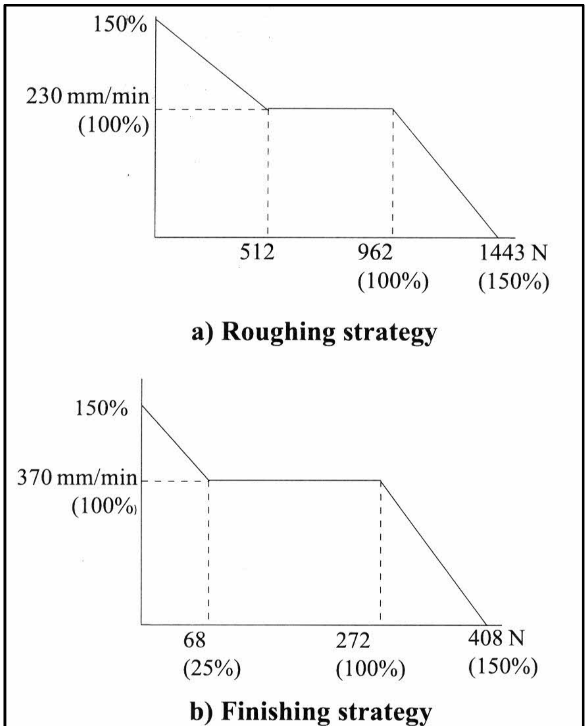

Fig. 6 Control strategies for feed-rate control

3 Micro-Cutting

The feature sizes obtained in micro cutting are usually in the range of 25-500 µm. For the features which are controlled by the tool size, the minimum tool size becomes the lower limit. The radius of the cutting edge of the micro tools is generally maintained in the range of 1-10 µm. In case of a single-point diamond tool, it is practically feasible to have an edge radius smaller than 1 µm (Lucca and Seo, 1993). The uncut chip thicknesses in micro cutting are recommended considering the edge radius, the type of machining operation and the tool-work material combination. Though micro cutting can be considered as a down-scaled version of conventional macro cutting, the domain knowledge available from the macro scale cutting process cannot be directly applied. The micro scale effects such as material strengthening due to size effect, effect of edge radius, microstructural effects (Moronuki et al., 1994; Weule et al., 2001), ploughing phenomenon and minimum uncut chip thickness (Venakatachalam and Liang, 2007, 2009) and spindle/tool run-out effects become very significant. Research into micro-cutting has gained momentum in the last decade with the availability of cutting tools and machine tools to carry out micro machining operations.

3.1 Review of literature on micro-cutting

In the literature review, only research papers dealing exclusively with micro-orthogonal cutting and micro end milling are presented.

3.1.1 Micro-orthogonal cutting

In comparison with macro orthogonal cutting, micro orthogonal cutting has been investigated with a greater focus on the role of cutting edge radius, as its influence on the deformation zones is significant when the uncut chip thickness is in the neighbourhood of edge radius value. As shown in Fig. 7, this condition creates a large negative rake angle. The material flow around the tool edge becomes quite complex. Friction conditions at the tool-chip interface also change considerably.

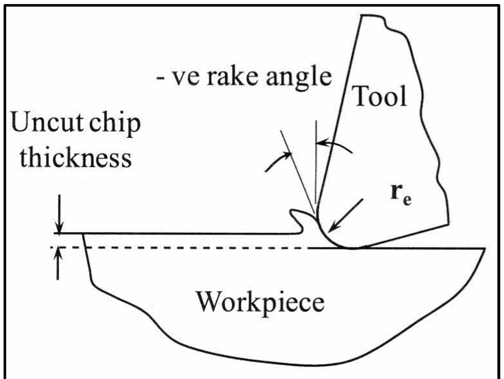

Fig. 7 Salient features of micro cutting

Edge radius effect and minimum uncut chip thickness: When the uncut chip thickness is smaller than the edge radius, the effective rake angle becomes highly negative even though the nominal rake angle of the tool is positive. Also the material flows along the edge radius with a separation at a point on the edge radius, called stagnation point. The material above the stagnation point flows upwards as chip along the effective rake face, while the material below the stagnation point flows beneath the rounded edge of the tool leading to the ploughing effect (Kim and Kim, 1995). In some investigations, the effect of edge radius is taken to change the effective rake angle (Bissacco et al., 2008).

It is possible to arrive at the stagnation point angle or minimum uncut chip thickness by analytical approach. Starting from Abdelmoneim and Scrutton (1974), a number of researchers have attempted to determine the stagnation point angle. Similar attempts are made to derive minimum uncut chip thickness by computer simulation in nano cutting (Ikawa et al., 1992). Yuan et al. (1996) have modelled minimum uncut chip thickness in micro cutting based on the friction coefficient at tool-work interface. Effect of friction coefficient on the minimum uncut chip thickness has been analyzed by Son et al. (2005). In a different approach, Liu et al. (2006) have developed slip-line field model to predict the minimum uncut chip thickness.

It is to be remembered that the uncut chip thickness can be derived from the stagnation point angle or vice versa. One can find values for stagnation angle such as 14° (Abdelmoneim and Scrutton, 1974), 30° (Manjunathiah and Endres, 2000),37.6° (Basuray et al., 1977),39° (Malekian et al., 2012) and 58.5° (Woon et al., 2008) in the published literature. It is generally agreed that the stagnation angle is influenced by the friction condition between the material and the tool face.

However contradicting findings are reported in the literature. Son et al. (2005) have reported that smaller edge radius and higher friction coefficient lead to lower value of minimum uncut chip thickness. However, Malekian et al. (2012) have reported that an increase in the friction between the material and the tool face increases the stagnation angle, thereby increasing the value of minimum uncut chip thickness. The difficulties in determining the uncut chip thickness experimentally in micro-cutting are brought out by Malekian et al. (2012). There is a real challenge in overcoming these practical difficulties and validating the theoretical predictions of stagnation point angle or minimum uncut chip thickness.

Material strengthening due to size effect: When the depth of cut is very small, the material exhibits higher strength and hence specific energy required in micro-cutting increases. Though the size effect in cutting as well as grinding has been investigated long before, the relevant mechanism could not be explained on the basis of plasticity theory which draws information from conventional mechanical tests involving tension, compression and torsion. According to Taylor hardening model based on conventional plasticity, square of the flow stress varies linearly with the density of geometrically necessary dislocations. It has been found that micro and nano- indentation tests dominated by strain gradient effect only are able to provide information about the material behaviour at the micro scale. Based on strain gradient plasticity, Gao et al. (1999) have proposed a framework in which both geometrically necessary and statistically stored dislocations are combined. Nye's factor of 2 suggested by Arsenlis and Parks (1998) for polycrystalline material is used to relate effective strain gradient to the density of geometrically necessary dislocation. Further, a more accurate value for the Taylor factor is used to relate tensile flow stress and critically resolved shear stress. The intrinsic material length scale derived by Gao and Huang (2001) is shown to determine the behavior of material at micro-scale. However, the strain gradient to be used along with the material length scale has to be determined from process mechanics concerned. Dinesh et al. (2001), by analogy with indentation, have proposed a method to include strain gradient in machining and arrived at the material strengthening due to size effect. Following the work of Dinesh et al. (2001), Joshi and Melkote (2004) proposed an approach to incorporate strain gradient dependence of flow stress, using an exponent to account for the contributions of statistically stored and geometrically necessary dislocations. An appropriate value of exponent is used to bring down the difference between predicted and experimental shear strength values.

In a paper published by Siddharth and Shunmugam (2012), the strain gradient is arrived directly from cutting mechanics, following the analysis of parallel-sided shear zone proposed by Tounsi et al. (2002). The results are validated using a limited number of constant uncut chip thickness experiments, taking the values of stagnation point angle and Merchant's machining constant as reported in the literature (Sidharth Rao, 2011).

3.1.2 Micro end-milling

Micro end milling is carried out using end mills having diameter less than 500 μm. The literature review is limited to flat end mill investigated in the present work. Even though micro end milling process is the scaled down form of the conventional end milling process, the application of the domain knowledge available from the conventional milling process into micro milling is not straightforward. At micro scale, there exists a phenomenological difference in the conditions between micro end milling and macro end milling operations. Due to complexity involved, the difference needs to be considered appropriately while modelling the process mechanics. As the tool diameter becomes smaller, the rotational speed required is theoretically very high to achieve the recommended cutting speed and keep the reasonable level of productivity (Bao and Tansel, 2000a). The feed per tooth to tool radius ratio is much larger than macro end milling operation, due to which the stress variation on the tiny shaft of the micro tool is much higher than that on a macro tool (Bao and Tansel, 2000a; Li et al., 2007). The run-out to tool diameter ratio is much larger for micro end milling than the macro end milling, as the diameter of end mills varies in the range of 100 to 500 μm (Bao and Tansel, 2000b). Higher feed rate per tooth to tool radius, tool run-out to tool diameter ratio's and unpredictable cutting action lead to rapid wear of the cutting tool and thus sudden tool failure (Bao and Tansel, 2000c). Homogeneity in the micro structure of the workpiece material, minimum thickness of cut and edge radius of the tool control the achievable surface qualities, magnitude of the cutting forces and chip morphology. Chip formation in micro milling is not continuous during a single cutting cycle (Ikawa et al., 1992; Weule et al., 2001; Vogler et al., 2004a & 2004b; Kim et al., 2004). The feed and depth of cut are very small (1μm/tooth and 100 μm) when compared with the conventional macro end milling process (100 μm/tooth and 1 mm) (Vogler et al., 2004a). In this section also, only literature on micro end- mill geometry, forces and surface finish is covered.

Cutter geometry: The micro end mills are always of solid construction with shank sufficiently larger than the end portion on which necessary cutting elements are provided. The peripheral cutting edge has a narrow land just behind it along the helical edge which may be relieved or not relieved. Certain features in the design and construction of the micro end mills may vary from one manufacturer to another. In any case, control of cutting edge radius in manufacturing is very important, as the uncut chip thicknesses may be of the same order. For end mills with sizes varying from 100 to 500 μm, the edge radius typically varies from 1 to 10 μm.

Micro end-mills are designed and developed to machine various materials and different workpiece geometries. End mill of different geometries have been developed by Fang et al., (2003) and Aramcharoen and Mativenga (2009), while Adams et at. (2001) and Aurich et al. (2012) have developed ultra-small micro end mills for special applications. Several studies have been carried out to assess the machining capability of end-milling process in the machining of pure copper (Rahman et al., 2001; Filiz et al., 2007), steel (Takacs et al., 2003; Schmidt and Tritschler, 2004; Uhlmann et al., 2005), brass and tungsten-copper composite (Uhlmann et al., 2005), glass (Arif et al., 2011), titanium alloy (Őzel et al., 2011) and tungsten carbide (Nakamoto et al., 2012). Machining of hardened tool steels used in die and mould manufacturing by micro milling is getting increased attention in the recent years (Bissacco et al., 2005; Aramcharoen and Mativenga, 2009; Ding et al., 2010). Since the micro end mills are tiny and slender, research has also been carried out to study the dynamic characteristics of micro end mills to have a greater insight into their performance (Fliz and Ozdoganlar, 2011; Mustapha and Zhong, 2013). Being a very versatile mechanical micro machining process capable of handling wide variety of work material and complex geometry, it is important to review the available literature dealing with the cutting forces and surface roughness in micro end milling.

Cutting forces: Analysis of cutting forces in micro end milling gives valuable information about the chip formation, effect of multi-phases, tool conditions and changes in contact conditions (Kim et al., 2004). Prediction of the cutting forces in micro end-milling helps to select optimal cutting conditions to obtain high machining quality and ensure long tool life (Vogler et al., 2003). Several modelling attempts have been made to predict the cutting forces based on different approaches. The cutting forces in micro end milling are modelled in terms of cutting coefficients and instantaneous uncut chip thickness considering the geometry of tool engagement. In general, there are two different of approaches in arriving at the coefficients used in the models. In one approach, the relevant coefficients are determined by FE simulation of micro orthogonal cutting. In the second approach, the coefficients are obtained experimentally from micro orthogonal cutting or directly from micro milling experiments. The coefficients are expected to include edge radius, minimum uncut chip thickness and material strengthening effects. While experimentally obtained coefficients reflect these effects, those derived from FE simulation depend on the model's capability to include such effects. Finally, the end milling forces in the feed and transverse directions are obtained using suitable transformations, as in the conventional end milling.

Bao and Tansel (2000a, 2000b) have used experimentally determined milling coefficient and estimated the cutting force signals with and without tool run-out. Considering the fact that micro end mill encounters different phases whose size may be of the same order as the uncut chip thickness and is sensitive to the variation in the property, Vogler et at. (2003, 2004b) developed a model for end milling forces with cutting coefficients determined from experiments as well as FE simulations of micro orthogonal cutting of multi-phase materials. In a different approach using slip-line field model, instantaneous uncut chip thickness considering elastic recovery is computed and cutting forces are predicted from orthogonal cutting process involving both cutting and ploughing actions. The tool misalignment leading to tilt and run-out as well as different phases present in the work material are also included in the analysis by some researchers (Jun et al., 2006a, 2006b).

Őzel et al. (2007) have taken the cross-section of end mill with edge radius and obtained cutting forces directly by FE simulation using the cutter trajectory. Being a 2D model, effect of helix angle cannot be included and it is as good as the orthogonal cutting with varying uncut chip thickness. Lai et al. (2008) have incorporated material length scale into Johnson-Cook material model and carried out FE simulation of orthogonal cutting with edge radius and minimum uncut chip thickness effects. Then, a slip-line model is developed to calculate the cutting forces using calibrated coefficients and minimum uncut chip thickness from FE simulations. Models for prediction of cutting forces have been developed by Park and Malekian (2009) and Malekian et al. (2009) by incorporating shearing and ploughing effects. In the work of Afazov et al. (2010), a non-linear relationship is established between forces and uncut chip thickness using the results obtained from FE simulation of orthogonal cutting process covering a wide range of cutting speeds. The cutting forces in micro end milling are determined from uncut chip thickness at a given instant, using appropriate transformation of forces predicted from the non-linear relationship. In a recent work, cutting force coefficients are evaluated by FE simulations of micro orthogonal cutting for a wide range of cutting edge radius and uncut chip thickness (Altintas and Jin, 2011; Jin and Altintas, 2012). In this work also non-linear functions connecting cutting force coefficients, uncut chip thickness and edge radius have been developed and used in the prediction of cutting forces in micro endmilling with suitable transformation. The material strengthening is not incorporated explicitly in the above two works.

Along with the efforts to arrive at the cutting forces from FE simulations, parallel efforts to develop analytical cutting force models for micro end milling have also continued. Zaman et al. (2006) have developed analytical expressions for cutting forces in terms of experimentally obtained coefficients and actual trajectory of cutter tip which determines the different zones of uncut chip thicknesses. In a different mechanistic approach, the effect of edge radius is included in the two force components of orthogonal cutting derived from Merchant's analysis as additional frictional forces at the flank face (Kang et al., 2007). In this model, material strengthening has not been considered. A three-dimensional force model for micro end milling has been developed using coefficients evaluated by curve fitting the measured forces (Li et al., 2007; Perez et al., 2007; Uriate et al., 2008). An analytical model for end milling forces has been developed by Bissacco et al. (2008) using the formulas for cutting coefficients reported by Armarego and Brown (1969) and edge radius effect is brought into the model in terms of rake angle change depending on the ratio of uncut chip thickness to edge radius. In this model too, material strengthening due to size effect is not included.

Siddharth and Shunmugam (20 I 2) have used a validated material model that takes into account the material strengthening and edge radius effects and arrived at the milling force coefficients on the basis of oblique cutting principles. They have considered single tooth engagement in predicting the force signals and compared with experimentally measured signals corresponding to two different feeds only in terms of average deviation of the signal amplitudes. Surface finish: Surface quality plays an important role in the performance of the component and therefore micro end-milling is required to produce a good surface finish on the machined surfaces, as secondary operations to improve surface finish cannot performed due to the small feature and/or component size. Surface roughness of the micro end milled surfaces, which depends on the cutting conditions and process dynamics, has been the focus of the researchers working in the area of mechanical micro machining.

The surface roughness obtained on different metals such as brass and steel (Takacs et al., 2003) and pure copper (Filiz et al., 2007) has been analyzed to assess the quality of surfaces produced in micro end milling. Statistical technique like RSM is used by Wang et al. (2005) to find the influence of milling parameters and predict the surface roughness in micro end milling. Optimum micro end milling conditions for obtaining the best surface finish have been identified by Aramchareon and Mativenga (2009) and Nakamoto et al. (2012) in hardened tool steel and tungsten carbide respectively. The influence of ratio of cutting edge radius and uncut chip thickness on surface finish has been investigated by the former authors, while the latter studied the effect of tool wear on surface finish. Yun et al. (2011) studied the surface roughness of the side wall of the milled slots under ploughing and normal cutting conditions during side wall-machining using micro end mills. The onset of ploughing is identified with the help of peak values of the measured cutting forces signal. When the chip formation is affected due to ploughing effect, elastic recovery of the workpiece occurs after the passing of the tool edge. Ozel et al. (2011) carried out micro end milling experiments on titanium alloy to identify conditions that would minimize both surface roughness and burr simultaneously.

A mechanistic model of surface roughness formation has been proposed by Vogler et al. (2004a) for single-phase material, considering geometric effect and process geometry along with uncut chip thickness effects. Comer radius on the end mill influences the surface roughness of the slot bottom along with minimum uncut chip thickness. The minimum uncut chip thickness to be used in the model is predicted from FE simulations. This approach has been further refined by adding stochastic nature of surface generation determined from experimental data and surface roughness generated on both side-wall and bottom surfaces in micro end milling are modelled (Liu et al., 2007a, 2007b).

The models developed above can be applied when the end mill is fresh. The surface roughness, however, needs to be monitored with machining time, as the tool wear affects the surface finish greatly. It must be remembered that a micro end mill has to produce several micro features on a given part and machine many more micro parts before it reaches end of its life. Since online measurement of surface roughness as well as tool wear is difficult, an indirect method is needed to detect the deterioration in the performance of the end mill. Tansel et al. (1998, 2000) have measured the cutting force signals with an objective of predicting tool breakage in their first paper, while analysis of force variation with tool wear has been the focus in the second paper. The cutting force signals thus obtained have been suitably processed to bring out the relationship with the tool wear.

3.2 Investigations into micro-end milling

Literature on micro end milling reveals that the material strengthening due to size effect and effect of edge radius are to be investigated and there is a need for good analytical models to predict cutting forces with the cutter rotation. Further investigations are also needed to understand the surface finish and relate the same with the process dynamics.

3.2.1 Micro-end milling experiments

The micro end-milling experiments are carried out on a high-precision KERN Evo machining center procured with a liberal financial assistance from DST and having spindle speed in the range of 500-50,000 rpm and 50,000-160,000. In addition, a miniaturized machine tool (MMT) developed indigenously with ARDB grant is also available for carrying out the micro-cutting experiments (Srinivas and Shunmugam, 2009; 2014a). The instruments with nano-level resolution such as Dektak 150 based on stylus profilometry (vertical resolution: 1 Å) and a noncontact 3D optical profiler WYKO NT1100 based on whitelight interferometry (vertical resolution: < 1 Å) are also used in addition to the existing micromeasurement facilities available in the metrology laboratory. A 5-component, piezo-electric type 'MiniDyn' 9256C2 dynamometer is used to measure the cutting forces with 0.002 N resolution. (More details can be seen at: http://mech.iitm.ac.inlFaculty/mss/home.php).

Extensive experimentation has been carried out using two-fluted helical solid carbide micro end-mill of 0.5 mm diameter and mild steel (AISI 1019) workpieces. Two important process characteristics, namely cutting forces and surface finish have been measured.

3.2.2 Analytical model for cutting forces

Material model: The reference flow stress σ_0 is taken to be a non-linear function of strain, strain rate and temperature as proposed by Johnson and Cook (1983).

$$\sigma_0 = f_0(\varepsilon, \dot{\varepsilon}, T) \quad (4)$$

where ε is the equivalent plastic strain, $\dot{\varepsilon}$ is the equivalent plastic strain rate (s^{-1}) and T is the working or absolute temperature in ºC. The relevant exponents, coefficients and constants needed in the above equation are obtained from Vedantam et al. (2005).

The values of plastic strain ε and plastic strain rate $\dot{\varepsilon}$ are to be determined from the process mechanics. Adapting the rectangular shear-zone model of thickness, the equivalent plastic strain ε and equivalent plastic strain rate $\dot{\varepsilon}$ are found along the main shear plane (Tounsi et al., 2002). This model requires shear, friction and effective rake angles. Shear angle φ is obtained from Merchant's equation (Shaw, 2003),

$$2\varphi = c - \beta + \gamma_{eff} \quad (5)$$

where c is the Merchant's constant. For mild steel work-material and high speed steel tool- material combination, its value is 1.31 (75°). Friction angle β can be found using the sticking and sliding friction model proposed by Ozlu et al. (2009). The effective rake angle remains as nominal rake angle, when the uncut chip thickness t_o is large in comparison with edge radius of the tool r_e. However, for $t_o \leq r_e(1 + \sin\gamma)$, the effective rake angle γ_{eff} changes (Abdelmoneim and Scrutton, 1974) as,

$$\gamma_{eff} = \sin^{-1} [(t_o / r_e) - 1] \quad (6)$$

The flow stress equation accounting for the effect of geometrically necessary dislocations can be written as,

$$\sigma = \sigma_0 (1 + \ell\eta)\ 1/2 \quad (7)$$

where ℓ is the intrinsic material length scale to balance the dimensions of strains and strain gradients and η is the strain gradient (Siddharth Rao and Shunmugam, 2012). Typical variation of shear strength (σ_0/3) with uncut chip thickness is shown in Fig. 6. More details can be obtained from Srinivas and Shunmugam (2014b).

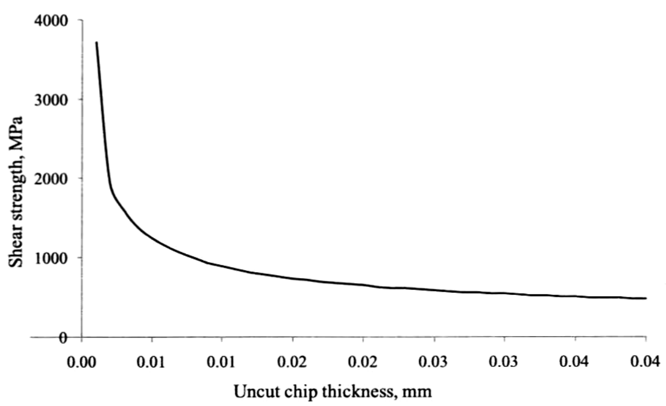

Fig. 6 Shear strength variation with uncut chip thickness in orthogonal cutting for a typical machining condition

Cutting Forces: Considering an elemental cutting edge dh, the cutting action can be envisaged as oblique cutting with the cutting edge having an inclination angle which is equal to the helix angle of the cutter (Fig. 7). The differential cutting force components in tangential, radial and axial directions are expressed as a function of varying uncut chip thickness and width of cut as follows (Altintas, 2000),

$$dF_t (\theta) = [K_{tc}\, t_c (\theta) + K_{te}]\, dh$$

$$dF_r (\theta) = [K_{rc}\, t_c (\theta) + K_{re}]\, dh$$

$$dF_a (\theta) = [K_{ac}\, t_c (\theta) + K_{ae}]\, dh \quad (8)$$

1st term is the cutting force component proportional to the area of cut, representing the shear and frictional forces in chip formation. 2nd term is the edge force component proportional to the width of cut, which represents the rubbing and ploughing at the cutting edge. The cutting force coefficients (K_{tc}, K_{rc}, K_{ac}) are expressed in terms of the modified mechanics of cutting approach of orthogonal to oblique transformation as proposed by Armarego and Brown (1969). The edge coefficients (K_{te}, K_{re}, K_{ae}) in tangential, radial and axial directions are computed from the relations suggested by Abdelmoneim and Scrutton (1974), taking stagnation or neutral point angle as 14°.

The elemental cutting forces are resolved along feed (X), transverse (Y) and axial (Z) directions, and substitution is done for instantaneous chip thickness $t_c(\theta) = f_x\sin(\theta)$ as given by Martellotti (1941) and width of cut $dh = - r d\theta/\tan a$, where f_x is the feed per tooth, r is the radius and a is the helix angle of the milling cutter.

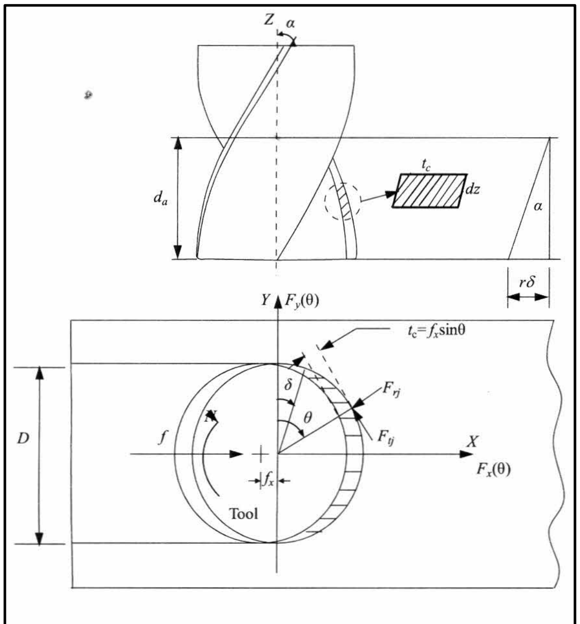

Fig. 8 Details of helical micro end-milling

The resulting equations are integrated analytically using the entry and exit integration limits (Srinivasa and Shunmugam, 2014). Normal rake angle to be used in the above equations is computed from the specified radial rake angle and helix angle is taken as the nominal rake angle (Armarego and Brown, 1969). Fig. 9 shows the cutting forces predicted as cutter goes through every incremental rotation. Point-to point comparison of the forces signals gives overall absolute average error between the predicted and experimental cutting forces in the feed (ΔF_x) and transverse direction (ΔF_y) as 12.79 % and 10.60 % respectively.

3.2.3 Surface finish

The regression analysis of surface roughness obtained in micro end-milling brings out the significance of cutting parameters. The statistical studies confirm that filtered resultant signals show greater correlation with the surface roughness and also signals filtered taking mechanistic model as reference can be used for online monitoring of surface roughness and deterioration in the surface finish as the end- mill wears out.

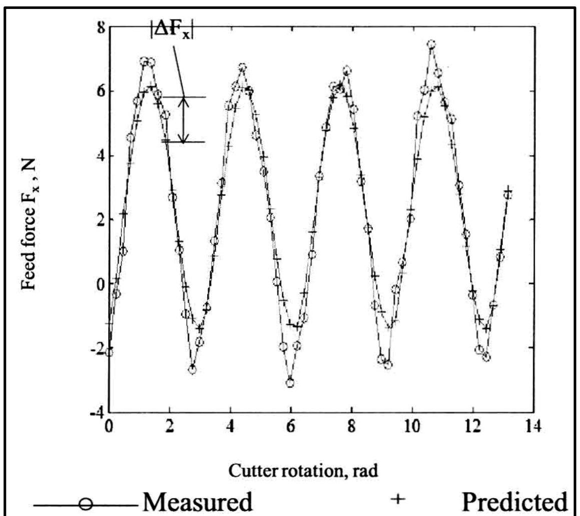

Fig. 9 Feed forces from experiment and mechanistic model for a typical machining condition

4. Conclusions

Based on literature survey, the challenges in macro-cutting and micro-cutting have been brought out in this paper. The research issues in macro endmilling and micro-end milling are discussed and the results of the investigations are presented.

• Knowledge in conventional macro-cutting has been used to implement adaptive control strategyin end milling operations for enhancing productivity and product quality.

• Micro-cutting facility established at IIT Madras can handle a variety of materials and complex shapes.

• Fundamental studies on material behaviour in micro-cutting have been carried. A fine-tuned material strengthening model taking into account the strain gradient effect in micro cutting has been developed.

• The study has been extended to develop mechanistic model of cutting forces in micro end milling.

• The facility can be used to produce metallic parts with desired micro features and used for further replication using appropriate methods.

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FREDERICK WINSLOW TAYLOR

1856 -1915

Frederick Winslow Taylor is accepted to be the father of Scientific Management and one of the most influential contributor of Classical Management School. According to many academicians, Taylor's System of industrial Management that is based on scientific Management has influenced the development of virtually every country enjoying the benefit of modern industry.

Taylor was an American Mechanical engineer who originally sought to improve industrial efficiency. A Management Consultant in his later years, he is sometimes called "The Father of Scientific Management". He was one of this intellectual leaders of the Efficiency Movement and his ideas, broadly conceived, were highly influential in the Progressive era.

Taylor was born in 1856 to wealthy Quaker family in Philladelphia, USA, Taylor wanted to attend Havard university, but it was not possible and in 1874 he became an apprentice pattern maker, gaining shop floor experience that would improve the rest of his caver. He obtained degree in Mechanical Engineering .He began Developing his Management Philosophies during his time at MIDVALESTEELWORKS, where he rose to be this chief Engineer of the Plant. He eventually became a Professor at the Tuck School of Business at Dartmouth College.

Taylor believed that the Industrial Management of his day was amateurish, that management could be formulated as an academic discipline and best results would come from partnership between a trained and qualified management and co operative, innovative workforce. Each side needed the other, and there was no need for trade unions. Taylor's Principles or frequently despairingly Taylorism consisted of four principles.

1. Replace rule of thumb work methods with methods based on scientific study of the tasks.

2. Scientifically select, train and develop each employee rather than passively leaving them to trained themselves.

3. Provide "Detailed Instruction and supervision of each worker in his performance of that worker's discrete task".

4. Divide work nearly equally between manages and workers so that managers apply scientific Management principles of planning the work and the workers actually performing the tasks.

Taylorism to TQM

Dr N Ravichandran

In this paper, the historical development process of Classical and Non Classical Approaches of Management has been analysed. He starts with back ground details of F.W. TAYLOR, followed by an introduction, wherein he highlights Definition of Management, Interpretation of Management and Four functions of Management. While studying the historical development of Management, the author brings to light early works, 19th, 20th, 21st, century contribution by various Management Gurus. He dwells in depth on the contribution by F.W TAYLOR and Henry Foyal. There is in depth exposure to the evolution of "The Scientific Approach, The Administrative and The Bureaucratic Approach, The Human Relation Approach. Then he moves on to focus on "Systems Approach, Contingency Approach, Chaos Theory.

As part of this paper he brings out clearly the Changing Business Scenario, the challenges in a global market place, and Total Quality Management as one of the approaches to steer the organisation in the ever changing global market place.

The author concludes highlighting the current relevance of various approaches - the Scientific Approach, the Administrative and the Bureaucratic Approach, the Human Relation Approach. Then he moves on to focus "Systems Approach, Contingency Approach, Chaos Theory and TQM and their relevance.

Total Performance Assurance in Indian Manufacturing Organizations: Opportunities and Challenges

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Abstract-In today's highly competitive industrial and business environment, development of a Total Performance Assurance System for any type of organization, particularly manufacturing organizations, with the capability of coping up with external disturbances and of creating a robust performance improvement and monitoring system with increasing profitability and market share being the primary goal is a necessity. In this context, the main conditions to be created by the management of any organization are manifold: strong knowledge management system at the operational and strategic levels, benchmarking products and processes, appropriate technology selection and adoption at all levels, identification and control of different types of 'losses' and flexibility in the manufacturing and production systems. Creating and controlling a holistic and integrated system for an organization incorporating all these specific conditions is essential for sustaining organizational performance in totality. A Total Performance Assurance System focuses on seven specific interrelated dimensions of performance viz. efficiency, effectiveness, quality, quality of work life, innovation, productivity and profitability.

For many organizations, the goal of improving the level of performance assurance on a continuous basis is set based on benchmarking initiatives. The performance of many internationally-renowned manufacturing organizations remains sustainable by adopting those approaches of management and operations control that have a direct bearing on the performance assurance-related conditions. However, there are instances where many organizations reaping the benefits of performing in a monopoly market world-wide have failed miserably with a fast-changing technology and business scenario in recent times. Referring to the problems being encountered by many Indian manufacturing organizations, the lecture highlights the specific steps to be followed for designing and implementing a framework for total performance assurance, the improvement opportunities the Indian companies may explore, and the challenges to be overcome by such organizations ill the Indian context.

Management of Manufacturing Operations

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F W Taylor is credited as the Father of Scientific Management. Taylorism as a word has come to stay to refer to the principles developed by Taylor. He is also credited with the development of the new branch of Engineering christened Industrial Engineering. The focus of Taylor's work was on Efficiency Management and improvement of Productivity. The development of incentive systems is based on the principle of getting higher productivity from worker. Taylor has been a Manufacturing Manager and his principles are based on his understanding of manufacturing systems.

Though the work of F W Taylor has been greatly appreciated even today (Taylor's 1911 book The Principles of Scientific Management, was acknowledged in 2001 by Fellows of the Academy of Management as the most influential management book of the twentieth century), there have been criticism as well. One of the criticisms of the labour unions and the communists has been that Taylorism subordinates the workers to management. Management Theorist Henry Mintzberg states that an obsession with efficiency allows measurable benefits to overshadow less quantifiable social benefits completely, and social values get left behind.

Taylor was very much concerned with cost of manufacturing and productivity. He also recognised the motivation of workers as important tool for improving productivity. Towards this end he developed systems, which later became the framework of Production Incentive. This was based on the premise that money is the prime motivator for workers.

However, the requirements and the environment of Manufacturing Systems have undergone substantial changes / shifts from the days of Taylor. The major focus of Manufacturing Systems in the days of Taylor was to produce. There has been a major shift on this dimension. The major focus of the Manufacturing Systems today is to deliver and not only produce. Delivery is more encompassing than mere production of goods. Delivery is multi-dimensional and dynamic. Accordingly, the present day manufacturing systems has to recognise and focus on delivery. This calls for Management of Manufacturing Operations to go beyond Taylorism and address the issues based on the situations and environment.

Delivery, which is the focus of Manufacturing Operations today, not only includes volume of output, cost of output; but also meeting market expectations, customer preferences, product characteristics, and such other parameters. Manufacturing being primarily a man-machine system; men has to align as per the dimensions of delivery. This necessitates men to be more participative rather than working based on instructions. Therefore, management of manufacturing operations has gone much beyond engineering and technology, which remain the basis of manufacturing. Management of human systems in an integrated manner with engineering and technology has also become a relevant issue in manufacturing operations. The human system in organisations, specifically in a manufacturing environment, is often referred as soft systems. Proper management of the soft systems contributes significantly to improvement in productivity and overall general performance of manufacturing system.

The issues are being illustrated with some case situations.

Toyota's effort to implant TMS (Toyota Manufacturing Systems) in American automobile plant is an interesting study. TMS is associated with high productivity and low cost automobile manufacturing. An effort was made to implant the practices of TMS in an automobile plant in USA in order to improve productivity and reduce costs, met with lot of resistance by the workers. The workers were backed-by the union. This was largely due to the fact that TMS did not recognise the practices and work habits that the local workers value or are used to. Subsequently, the TMS was modified to incorporate the values of the workers. This resulted in improvement of productivity and. also greater participation of the workforce in the manufacturing operations.

The next case also refers to Toyota. Toyota invests heavily in R&D. It regularly has minor and major changes in its manufacturing systems to remain ahead of competition and also improvement in delivered products. The output of R&D is expected to feed the production in a seamless manner to bring out improved product in terms of performance and cost. R&D is given high priority in Toyota to give competitive advantage. It was realised that though the R&D comes out with expected outputs, but it takes substantially long time to get incorporated in products. After a detail analysis it was identified that the organisational set up is the limiting issue. This issue was never given due importance in the past. The organisational set up was changed in mid 1990s to bring R&D closer to the relevant manufacturing unit to derive full advantage of R&D efforts. Since then it has become a regular practice to address the organizational issues at Toyota.

In many situations, due to absence of competition and in an imperfect competitive situation, the manufacturing is unable exploit its full potential or pursues not so desirable goals. A case in point is that of a public sector enterprise which largely caters to defence requirements and high end earth moving equipments and rolling stocks. The objective of the organisation has been primarily to focus on meeting the physical demand. This resulted in not so productive use of the potential of the facilities and resources at its command. This resulted in a difficult situation for the organisation when it faced competition for its products. The situation brings in focus the importance of delivering the requirements as per the environment and not merely meeting physical output.

The value system of the workers is another aspect needs to be considered in a manufacturing operations rather considering men (worker) as another input for production. In Britain, a continuous operation of manufacturing plants, like steel plants and other similar process plants, operates only for 50 weeks in a year and not 52 weeks (365 days - 8760 hours) as in India. This is due to the fact that workers in Britain values 2 weeks' vacation (one week during Christmas, and one week during Easter) as more important than industrial output. Similarly, the duration of each of the shift is not same (8 hours per shift) and is 7,8, and 9 hours for morning, afternoon and night shifts respectively. This is again to take care of value system of workers.

There are many such cases all over the globe. In a CIS country (erstwhile USSR), the focus was always on production. This led to a difficult situation when these plants had to operate in free market situation facing global competitiveness. The plants did very well with a Brigade System of shop floor practice. It produced the desired output even under compelling situation. However, the same system became highly unsuitable under free market situation. The situation called for shutting down of uneconomic units, rationalisation of workforce and the like. These were achieved through active involvement of workforce by educating the workforce, retraining, and getting them involved in the decision making process.

Nearer home, there have been many situation in respect of technological changes, implementation of incentive plans for improved performance, and the like; which did not come up to deliver the expected results.

The above cases brings in focus that the Management of Manufacturing Operations is much more complex than suggested by Taylorism. While manufacturing is a man - machine system, Taylorism tries to get the highest output possible by the machine systems by drawing up a mechanism for the men to perform in a manner to achieve the same. Today manufacturing is much beyond the man-machine system and is influenced significantly by the environment (social, economic, political, and such other). It is in this context that manufacturing has to deliver in order to address the need rather than merely produce. In the man - machine system, man (workers/ employees) has to be given same importance as for machine. While managing machine is relatively easy to manage through principles of engineering and technology, it is somewhat difficult for human system. It must be recognised that individuals are autonomous in their behavior.

Dealing with man (workers/ employees) necessitates specific approach in each situation rather than applying generic principles. They are to be treated as equal partner in the manufacturing operations. They do not look for sympathy but empathy, i.e. recognising the value system they have, like any other groups or individuals; rationality in decision making rather than preference of the decision maker; importance to local societal issues, local laws, and the like. Treating men as equal partner in the manufacturing process and decision making is an important aspect of manufacturing operation today. An effort in empowering (as opposed to delegating) the workforce goes a long way in successful management of operation.

As manager of manufacturing systems, one has to focus on some of the following:

- look beyond engineering and technology
- treat men as equal partner in the system and get them involved
- delivery being the concern; familiarity with cost and market is essential
- familiarity with governing law including those related to personnel management
- co-ordination with other disciplines of the organisation
- sharing information with workers and other units
- and the like.

To sum up, while Taylorism is important in managing efficiency of manufacturing systems, one has to go much beyond to achieve effectiveness, which is equally relevant. This calls for flexible, broader and situational approach for Management of Manufacturing Systems.

Emerging Tools and Technics for Production Engineers

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F W Taylor is a legend and a proponent, and considered as the Father of Scientific Management and Industrial Engineering. He pioneered in and focused on the following approaches

- Scientific Observations
- Time study
- Best Methods
- Standardizations
- Productivity

Which resulted in phenomenal improvements in Industrial Efficiency offer benefits both workers and management.

Taylor's Principles

- Scientific study replacing rule-of-thumb methods.
- Focused selection, training and development of each employee.
- Monitoring the work and performance of each task by providing a detailed standard operating, procedure.
- Distribute work uniformly throughout the organization with managers focusing on mental tasks such as scientific management and meticulous planning and the workers focusing more on physical tasks.

Though Mr Taylor lived more than a century ago, his principles are still the best practices for the present manufacturing industry.

However, the world has moved on in terms of toots employed from a mere stop watch in those days to sophisticated and complex tools resulting in scientific prediction of

- Optimum process
- Cycle times
- Efficiency
- Productivity
- Energy
- Environment

The essence of Taylorism is preserved in these tools and technics. This paver is all about case studies of such tools being used by the anther to meet the day to day challenges faced in the field of manufacturing.

The manufacturing sector is undergoing serious changes amidst the global economic challenges. These emerging tools and technics will be helpful for the production engineers to overcome the hurdles and stay relevant for the future.

The first few interesting case studies focus on the design optimizations to preempt uncertainties and losses in the process to be developed.

The simulation tools paved way for real life problem solving in the die casting industry and created opportunities for

- New Product Design and Feasibility Improvement
- Flow Simulation
- Re-engineering
- Failure Mode Evaluation
- Root Cause Identification

The second set of case studies will focus on Process optimizations akin to the times of Taylors viz., time and motion study, time and cost estimations. But the present day technics and tools predicts them very accurately even before the process is developed there by avoiding delays and losses in terms of time and cost.

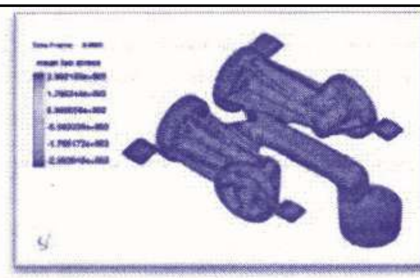
Optimum light is essential for the health, safety and productivity at the same time the energy needed to be conserved. The last few examples will highlight the tools and technics applicable to energy efficiency and environment.

These examples will not only demonstrate the effectiveness of the various techniques but also their simplicity in use and the numerous practical areas of application.

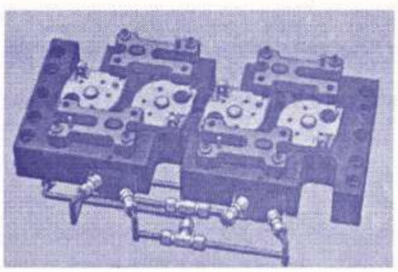
The vast experience and the effective use of various tools have made the author a pioneer in this field. Having seamlessly integrating these simulation processes in hundreds of developments so far, the author has got Jot of capabilities and wisdom to share with the user community.

The objective of the presentation is to rekindle, energize and encourage the fellow manufacturing fraternity to use more and more of these tools and technics on day to day applications of problem solving, resulting in time and cost savings.

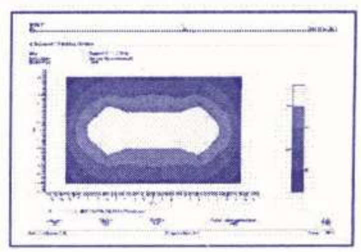
Flow Simulation Result – Half way through the Filling Cycle



Mean iso-stress Distributions – After Solidification in the Die



Optimized Hydraulic Fixture Simulation



ISO contours of light distribution

About Production Engineering Division Board

The Production Engineering Division of The Institution of Engineers (India) was constituted in the year 1984. This Division consists of quite a large number of corporate members from Government, Public, Private Sectors, Academia and R&D Organizations.

Various types of technical activities organized under the aegis of Production Engineering Division, which include All India Seminars, All India Workshops, Lectures, Panel Discussions etc., held at various State/Local Centres of the Institution. Apart from these, National Convention of Production Engineers, an Apex activity of this Division is also organized each year on a particular theme approved by the Council of the Institution. In the National Convention, several technical sessions are arranged on the basis of different sub-themes along with two Memorial Lectures in the memory of '**F W Taylor**' and '**G C Sen**', doyens in the field of Production Engineering, which are delivered simultaneously by the experts in this field.

Due to multi-level activities related to this engineering discipline, this division covers different sub-areas such as:

- Lean Manufacturing
- Cellular Manufacturing
- Rapid Prototyping
- Nano-technology for Industrial Applications
- Micro Finishing and Allied Operations
- Bio Inspired Manufacturing
- Process Optimization and Control
- Sustainable Manufacturing
- Green Manufacturing
- Digital Manufacturing
- Surface Engineering and Micro-machining
- Micro and Nano Robotics
- Online Multi Sensor Condition Monitoring
- Fractal, Bionic and Holonic Manufacturing

In order to promote the research and developmental work in the field of Production Engineering, the Institution also publishes **Journal of The Institution of Engineers (India): Series C** in collaboration with M/S Springer which is an internationally peer reviewed journal. The journal is published six times in a year and serves the national and international engineering community through dissemination of scientific knowledge on practical engineering and design methodologies pertaining to Mechanical, Aerospace, Production and Marine Engineering.

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