Made in my India

THE PAST, PRESENT AND FUTURE OF INDIAN MANUFACTURING INDUSTRY

B. Ravi
Pushpa Trivedi

Professor B Ravi receiving the We Think for India Foundation award
from then Prime Minister Mr. A. B. Vajapayee in New Delhi

Team members - left to right, back row: TV Ravikumar, B Ravi, Pushpa Trivedi;
front row: Manish Jain, Manish Jalan, Rahul Gupta

Made In My India

THE PAST, PRESENT AND FUTURE OF INDIAN MANUFACTURING INDUSTRY

B Ravi and Pushpa Trivedi

with Manish Jalan, Manish Jain,
Rahul Gupta and TV Ravikumar

Views expressed in this document are personal views of the team members and do not necessarily represent the views of the Institutions to which they belong.

ABSTRACT

Manufacturing industry is the engine of economic growth of a nation. It includes all activities in product life, starting from customer inputs for concept design, through conversion of materials and ending with product disposal. These activities provide gainful employment, create the products required to maintain and improve the standard of living and generate the wealth required for future development.

India can and will transform itself into a developed nation through the growth of its manufacturing industry, but this must be achieved in a *responsible and sustainable* manner, creating a role model for other developing nations. Conventional prescriptions emphasizing increased technology transfers, infrastructure projects, tax incentives and R&D spending are not sufficient to ensure manufacturing competitiveness – continuous improvement in price, quality and response. We therefore need a comprehensive *vision*, long-term *mission* and novel *policies* for sustainable growth of the manufacturing industry, evolved after a study of the past, present and future factors.

The history and geography of manufacturing reveals the influence of waves of technology, local resources and conditions existing in different countries at different periods. We also note that ancient India gave science and engineering to the world and medieval India was the leader in manufacture and exports of textile and metal products. At present, however, with less than 1% share of global trade and a poor rank in terms of competitiveness, India has to move aggressively to catch up with other nations.

The future manufacturing industry will be driven by global cooperation and intellectual property rights. Technological drivers include artificial intelligence, green materials and direct manufacturing processes. To ride these waves, new vehicles will be needed: bionics, reverse engineering, continuous innovation, knowledge management and product life-cycle engineering. These will lead to entirely new products and processes.

The vision is to *create and regenerate all types of wealth* – material, natural, intellectual and cultural – by encouraging and supporting appropriate manufacturing activities that respect nature and maintain a balance among various resources. This can be achieved through a mission to identify, train, deploy and support *manufacturing leaders* – individuals as well as firms. The policies to achieve these are presented as the interfaces between the Government, academia and industry.

The *Government and academia* ought to work together to create ‘respect for manufacturing’ and a suitable environment for manufacturing knowledge workers (seekers, keepers and users). Discovery of ancient knowledge from scriptures as well as creation of new knowledge through science and technology has to be promoted. Government and academia also need to work closely with the media, to reinforce the positive image of manufacturing sector, create awareness about present challenges and future technologies, and bring the leaders into limelight so as to inspire others.

The *academia and industry* should work together to identify the leaders and create innovative ideas for further exploration. They need to set up joint innovation centers, mutual exchange chairs (industrialist teaches in university; professor conducts research in industry), and compulsory internship for engineering students in industry. Industry should create exciting jobs for such students. Financial rewards must be made equivalent to those in other professions for a similarly qualified person to attract and retain talent of high caliber to manufacturing.

The *industry and Government* bodies together need to create a favorable environment for entrepreneurs to commercialize new product/process ideas, especially in high growth or strategic areas. Scientists in Government research labs may evaluate project proposals forwarded by financial institutions, assist in pilot production and further guide by joining the board of directors of manufacturing firms. The cooperative model, very successful in diary sector, should be applied to manufacturing clusters to promote common research, training and marketing, and benefit from economies of scale. They should be allowed to decide and create the local infrastructure best suited to their needs in partnership with the Government.

India has a natural advantage in two areas because of local availability of raw materials, suitable manpower and a large domestic as well as export market: (1) *agri-centric labor-intensive* products like convenience and health foods, and (2) *metal-based engineering-intensive* products like automotive castings.

The global competence and confidence gained by Indians in *Information Technology* must be used for eliminating, automating, speeding and value-addition in tasks related to design, production and supply chain management. Major bottlenecks – lack of awareness, inadequate technical support and high cost – can be overcome through training programs, indigenous development of IT solutions and (temporary) financial incentives. This will provide an additional competitive edge.

The document evolved through a series of brainstorming sessions by an interdisciplinary team of people, then supporting the logic with references and data. Still, this work is just a tiny thread of thought processes, and must be woven with those from others. We sincerely hope that students, teachers, researchers, practicing engineers and policy-makers will find some interesting nugget to explore further.

Mumbai, July 2003 Team members

CONTENTS

Abstract 02

1. Manufacturing for Wealth Creation 07

1.1 Defining manufacturing
1.1.1 Product life and cycle
1.1.2 Classification system
1.1.3 Relationship with other sectors

1.2 Development and various forms of wealth
1.2.1 Material wealth
1.2.2 Natural wealth
1.2.3 Intellectual wealth
1.2.4 Cultural wealth

1.3 Role in wealth creation

2. History and Geography of Manufacturing 19

2.1 Evolution of manufacturing
2.1.1 First wave
2.1.2 Second wave
2.1.3 Third wave

2.2 Growth of major sectors
2.2.1 Metal and automobile
2.2.2 Textile and paper
2.2.3 Petroleum and chemical
2.2.4 Computer and communication

2.3 Indian manufacturing industry
2.3.1 Ancient India
2.3.2 Medieval India
2.3.3 Post-Independence
2.3.4 Last decade

3. Future Drivers and Enablers 35

3.1 Economic drivers
3.1.1 Globalization and regionalism
3.1.2 Intellectual property rights

3.2 Technological drivers
3.2.1 Artificial intelligence and awareness
3.2.2 Green materials
3.2.3 Direct manufacturing

3.3 Methodologies (enablers)
3.3.1 Bionics and reverse engineering
3.3.2 Continuous innovation
3.3.3 Knowledge management
3.3.4 Product life-cycle engineering

4 Manufacturing Policy Framework 46

4.1 Vision and mission
4.1.1 Vision: balanced wealth creation
4.1.2 Mission: leaders for manufacturing
4.1.3 Policies for manufacturing

4.2 Respect for manufacturing
4.2.1 Favorable environment
4.2.2 Knowledge creation
4.2.3 Role of the media

4.3 Leaders for manufacturing
4.3.1 Innovation centers
4.3.2 Mutual exchange chairs
4.3.3 Compulsory internship

4.4 Synergic manufacturing
4.4.1 Focus sectors
4.4.2 Proof to product
4.4.3 Cooperative clusters

4.5 Information technology
4.5.1 Design activities
4.5.2 Production activities
4.5.3 Supply chain management

5 Conclusion 70

References and data sources

Authors' Profiles

If I were to look over the whole world to find out the country most richly endowed with all the wealth, power and beauty that nature can bestow – in some parts a very paradise on earth – I should point to India. If I were asked under what sky the human mind has most fully developed some of its choicest gifts, has most deeply pondered on the greatest problems of life, and has found solutions, I should point to India.

– F. Max Müller

In the West we have built a large, beautiful ship. It has all the comforts in it, but one thing is missing: it has no compass and does not know where to go. Men like Tagore and Gandhi and their spiritual forebears found the compass. Why can this compass not be put in the human ship so that both can realize their purpose?

– Werner Heisenberg

India, when independent, will embrace the materialism of the West and attain material prosperity to such an extent that it will surpass its past records in that field. Countries such as America would become increasingly spiritual because they will have realized from the height of material prosperity the simple truth that gross materialism cannot give eternal peace.

– Swami Vivekananda

For the society to prosper there are two important needs: prosperity through wealth generation and cherishing the value system of the people... The fact that we advance technologically does not preclude spiritual development. We need to home-grow our own model of development based on our inherent strengths.

– A.P.J. Abdul Kalam

1 MANUFACTURING FOR WEALTH CREATION

In this section, we first define manufacturing and classify different types of manufacturing. We will also study its relation with other sectors of economy and review its role in national development, including creation of different types of wealth.

1.1 Defining Manufacturing

Manufacturing can be defined as physical and/or chemical transformation of materials into products on a large scale using machinery or capital equipment, in contrast to production of hand-made goods for personal use. The products provide utility or satisfaction to human/living beings. They may take the form of final consumption goods, semi-finished goods (parts and raw materials) or capital goods (used for making final products). Associated activities such as blending of materials, assembly of components, and finishing (painting, heat-treating, packaging, etc.) are also treated as part of manufacturing. Let us examine this definition further and see the extent to which it will be meaningful in future.

From an engineering point of view, one can conceive of two types of products: discrete products (e.g., chair and phone) and continuous products (e.g., sugar and paper). The manufacture of discrete products includes the processing of materials, fabrication of components and sub-assemblies (intermediate products), and the assembly of final products. There is no such assembly activity in continuous products, which involve a series of conversions starting from raw materials. Some products, *e.g.*, a bottle of pills, combine both types of products: continuous, followed by discrete. New technologies such as free form fabrication are gradually blurring this distinction. In future, continuous processes may manufacture many discrete products.

The actual act of production (conversion of materials into usable form) is getting more and more efficient and automated, especially in developed countries. This is associated with reduced costs, lead-time and labor. The focus and investment of resources (finance and employment) is shifting to other activities in product development as well as services. For example, considerably larger time is spent in designing a modern aircraft and managing its supply chain logistics than in its manufacture.

The traditional definition of manufacturing associates it with economies of scale, implying standard parts. This is owing to the high cost of research and development, tooling and production facilities for a specific product, which need to be amortized over a large number. Thus, exclusive and custom-made products are expected to have high value and cost. This gap is asymptotically reducing to zero because of flexible and direct manufacturing systems. Mass manufacturing is giving way to mass customization.

An original equipment manufacturer (OEM) is understood to be a place where labor, materials and machines converge to produce finished products. The term OEM is not suitable for continuous products and will not be used hereafter. In contrast, supplier firms are understood to be those, which create semi-finished products, components or materials for use by the main manufacturers. First-tier firms supply to the final product manufacturer, second-tier firms supply to the first-tier firms, and so on.

The manufacturing activities (main as well as suppliers) require an array of support and service activities. The vital ones include energy supply, equipment maintenance, transportation (for raw materials, semi-finished and finished products), marketing (including customer research and advertisement), reselling (to an intermediate or final customer), finance (borrowing, accounting, saving), human resource management (from hiring to firing), information & knowledge management and legal (covering virtually every activity). In the past, firms tended to perform all the activities themselves – referred to as vertical integration – with handsome returns and growth. The increasing complexity of support and service activities (beyond a critical point) swung the trend in the opposite direction. Manufacturing firms started focusing on their 'core' competence and activity, outsourcing 'non-core' activities to specialized firms. However, the steep growth and fall of service firms, especially those related to information technology, may lead to other patterns in future.

1.1.1 Product life and cycle

The traditional definition of manufacturing focuses only on the act of production: starting from raw materials, conversion through a number of stages, and ending with assembly and testing. A more comprehensive definition includes all activities in product life, starting from customer inputs for concept design, and ending with product disposal (including repair and recycling). Let us look at these briefly.

The first step is the expression of a need that could be actual as in the case of 'market pull' products (clothes' ironing machine), or perceived as in the case of technology-push products (virtual reality systems). This is converted to product requirements using techniques such as Quality Function Deployment by market researchers. Then industrial designers take over and generate concept designs for shape and function. The engineering design team analyzes the selected concept to finalize the material, geometry and quality specifications. Virtual and real prototypes are fabricated and tested to validate the design. This is followed by the development of product-specific tooling, process plans and manufacturing facilities, if necessary. Trial productions are carried out to fine-tune the process parameters, and regular production starts. This involves manufacture of components, joining, assembly, finishing, inspection and packaging. The product is shipped to intermediaries and eventually to the customer.

This is however, only the beginning of the real life of the product. The product is used for its intended (and sometimes unintended) purposes, usually consuming energy. It may require timely maintenance and sometimes unexpected repair work. Some of its parts may be replaced, because of functional or aesthetic reasons. The ownership may change. Finally, when the product has outlived its life because it cannot function any more or because significantly improved new products are available, then it is discarded. It may be disassembled and the components are reused (in another product of the same type), recycled (another application) or simply dumped. In general, the real cost of the product (including its energy consumption, maintenance, upgrading and impact on environment) may be several orders of magnitude than its purchase price.

1.1.2 Classification system

The traditional classification system is based on the specializations of firms. The list has been standardized and adopted by various bodies, such as United Nations and European Union, to facilitate international comparison. The list of manufacturing sectors includes food, textile, chemical, automobiles, electrical machinery, telecommunication, etc. (see Table 1.1).

The industries dominating at the time of classification exert a significant influence compared to nascent industries, which are tiny but have a great potential for growth. Thus, it is quite possible that in future, the size of tobacco industry may gradually diminish (owing to government regulations and social norms) and merge in the food products category. On the other hand electrical, electronic and computing equipment and their sub-categories (say, food processing equipment) may rapidly grow to claim separate categories.

Table 1.1: Manufacturing sector

Code	*Products*
15	Food products and beverages
16	Tobacco products
17	Textiles
18	Textile products including wearing apparel
19	Leather, leather products and footwear
20	Wood, wood products
21	Pulp, paper and paper products
22	Printing and publishing
23	Coke and petroleum products
24	Chemicals and chemical products (including pharmaceutical)
25	Rubber and plastics products
26	Other non-metallic mineral products
27	Basic metals (ferrous and non-ferrous)
28	Fabricated metal products, except machinery and equipment
29	Non-electrical machinery and equipment
30	Office, accounting and computing machinery
31	Electrical machinery and apparatus
32	Radio, television and communication equipment
33	Medical, precision and optical equipment
34	Motor vehicles
35	Marine vessels, aircraft, spacecraft and railroad
36	Furniture products
37	Recycling

Source: STAN Industry List, http://www.oecd.org

The above classification assumes vertical integration in any sector. In reality, any given sector requires a high level of specialization for various activities such as product design, production equipment development, process planning and marketing. On the other hand, there is increasing similarity between the methodologies and technologies used for such specialized activities even across sectors. For example, computer-aided tools (such as virtual reality visualization and finite element analysis) and market research tools (such as quality function deployment) can be used for wood products, plastics products and metal products, which span different manufacturing sectors. This calls for a different classification system based on specialization in terms of activity (or process) rather than the product.

Another development is that service firms are talking about their products (such as a new insurance scheme), and manufacturing firms are offering their products as services. An example of the latter is that an end-user may purchase a computer or a photocopier as a service instead of as a product. The manufacturer delivers the machine, maintains it (including upgrading) and eventually takes it away (buy back options) when the user wants it no more. In future, all products and services may be lumped together as services. A particular service may comprise a series of steps involving products and services.

Depending on the needs of the end-user, the products and services can be classified as (a) basic needs: required for maintaining life with bare necessities such as food, apparel, shelter, commuting and communication; (b) comforts: to improve the standard of living, including automatic food processing equipment, refrigerators, air conditioners, television, music systems, etc.; and (c) luxuries: to improve the quality of life, such as decorative items.

The products may also be classified based on the type of resources and the level of technology involved: (a) labor-intensive natural products, such as minerals and farm produce, (b) skill-intensive low technology products such as shoes and textiles, (c) material-intensive intermediate technology products such as automobile components, and (d) high capital and technology intensive products such as robots.

Another classification can be based on the type of user (say, by age and gender) and level of user (individual, family and activity group). A third system can be based on the number of levels from the end-user. Thus fertilizer manufacturers cater to the needs of farmers, who in turn produce agricultural products, which are in turn processed by food-processing firms into the final product, consumed by end-users.

The above developments: specialized activities within any sector, product complexity and level of technology involved, and user-centric solutions (products or services) may lead to entirely new systems of industry classification in future.

1.1.3 Relationship with other sectors

Economic activities can also be viewed as primary, secondary and tertiary. Primary activities include cultivation and exploitation of natural resources; *i.e.*, agriculture, forestry, fishing, livestock, mining, quarrying and oil-exploration. The secondary sector essentially constitutes manufacturing activities, which take the output of primary industries and convert them to consumer and capital goods. Finally, tertiary sector constitutes service activities of the economy (Table 1.2).

Historical patterns of economic development indicate that in the initial stages of development of a country, a large proportion of national income is derived from the primary sector and also the labor force is heavily dependent on the primary sector. As an economy moves on to the industrialization process (due to increased productivity in primary sector), manufacturing sector starts growing and the labor released from primary sector is absorbed into manufacturing or secondary sector. Concomitant to this, the contribution of manufacturing sector to national income also increases. When the manufacturing sector develops and is on its way to maturity, it generates demand for services and in the final stage of development it is the service sector that becomes a major contributor to both national income and employment. Thus, the development process first satisfies the commodity needs of human beings and it is only when these needs are met, the service needs start emanating.

Table 1.2: Sectoral classification

Code	*Services*
01-05	Agriculture, hunting, forestry and fishing
10-14	Mining and quarrying
15-37	**Manufacturing**
40-41	Electricity, gas and water supply
45	Construction
50-52	Wholesale and retail trade
55	Restaurants and hotels
60-63	Transport and storage
64	Post and telecommunication
65-67	Financial intermediation and insurance
70-74	Real estate, renting and business services
75	Public administration and defense
80	Education
85	Health and social work
90-93	Other community, social and personal services

Source: STAN Industry List, http://www.oecd.org

India's development pattern has differed from the historically observed development pattern (see Table 1.3). In India, though service sector has become the major contributor to national income (due to the availability of highly skilled personnel and relative scarcity of capital), a significant proportion of labor force has still not found jobs in secondary and tertiary sectors and therefore has to depend on primary sector. In 1999-2000, Out of about 400 million workers employed in Indian economy, 60% were employed in agricultural sector, 12% in manufacturing sector and 28% in service sector [Economic Survey, 2001-02].

The high proportion of population engaged in a single sector and its contribution to national income has aroused concern in several quarters. A glance at Indian (post-independence) history reveals that planning process accorded high priority to the industrial sector and currently the emphasis is on the service sector. Attention to agricultural sector was paid, as and when it became a dire necessity. While we have been getting ourselves organized in primary production, the technology changed at rapid pace, and all of a sudden we found ourselves taking a leap to the tertiary sector, stealing a few decades from the manufacturing sector.

Table 1.3: Sectoral contribution to GDP (percentage share)

Sector	*1951-52 to 1955-56*	*1985-86 to 1989-90*	*1999-2000*
1. Agriculture	54.9	32.8	23.2
2. Manufacturing	11.9	20.0	17.1
2.1 Registered mfg	5.5	12.1	11.3
2.2 Unregistered mfg	6.4	7.9	5.8
3 Residual (services)	33.2	47.2	59.7

Source: http://planningcommission.nic.in, National Accounts Statistics, CSO.

For the development of a nation, all sectors have to move in tandem with each other. One could argue that, we are self sufficient in agriculture and are making good money in service sector and what is wrong about it? If Swiss can live on watches, why can't we on IT enabled services? To answer this question we need to look how the three sectors interact with each other. Agriculture is becoming more and more technology oriented and as the level of prosperity of our country increases, the human intensiveness is becoming increasingly costlier. For the agriculture to grow, we need more value addition. Sugarcane production needs to be complemented by sugar factories. Sunflower export alone does not pay enough, the population and its expectations have increased: we need sunflower oil extractors, and so forth. Any improvement in the efficiency of primary sector frees a portion of human capital hitherto dependent on it. For such capital to be involved in productivity of the nation, there is a need for creation of opportunities, which can be found in higher levels of industries.

Service sector is a consumer oriented sector and relies heavily on the domestic or foreign demand to sustain itself. A big portion of domestic demand consists mainly from those by urban middle to upper class, which is only a small portion of India and hence, growth of service sector needs to support rather than be regarded as a substitute for Indian manufacturing industry. Service sector breeds on robust primary and secondary sector for any economy that underlines the importance of manufacturing industry. An estimated 70% of service sector worldwide depends on the manufacturing sector.

1.2 Development and various forms of wealth

Before we explore the relationship between manufacturing activities and material wealth creation, let us examine the definition of wealth. The notion of wealth as proposed by Adam Smith (1756), widely accepted until recently, encompasses only a part of material wealth in the form of goods. The ultimate goal of wealth – ensuring the prosperity and well being of current as well as future generations – is often clouded by over-emphasis on material wealth, often at the cost of other forms of wealth. Material prosperity and wealth cannot provide solutions to human problems and in fact, these may pose a threat to the very survival of human beings in the long run. In view of this, the concept of sustainable development has gained currency over material prosperity. Sustainable development is defined as ensuring a better quality of life for everyone, now and for generations to come. It implies meeting the needs of the present without compromising the ability of future generations to meet their own needs. Key elements include effective protection of the environment and maintenance of high and stable levels of economic growth and employment. In a similar vein, the Endogenous Growth theory postulates link between economic growth (material wealth) and human capital, technology and physical capital as inputs in the growth process.

There is an obvious need to evolve a better perception of development process (outcome), which should encompass the links between material, natural, intellectual and cultural wealth (inputs). Material wealth is the most visible form of wealth and can be measured in terms of the current assets and future purchasing capacity. On the other hand, natural wealth has to be converted into material wealth through manufacturing activity. It is here that the conflict and imbalance between the material wealth and preservation of natural wealth becomes the focal problem in developmental process. Intellectual wealth or human capital has to be embodied into manufacturing activities for income and material wealth generation. Finally, cultural wealth provides the foundation and environment to create and sustain intellectual and other forms of wealth.

All types of wealth are complementary to each other and every nation must strive to achieve a balance among them. Nations with imbalance and disproportionality in different forms of wealth may find it difficult to survive in the long run, both individually and collectively. Due to complementarity (or imperfect substitutability) of various forms of wealth, nations that are materially rich and culturally poor, or naturally rich but intellectually poor may find it difficult to progress with the help of fair and democratic means. Let us look at these four types of wealth in some more detail, in particular, the factors that influence their generation and use.

1.2.1 Material wealth

Material wealth is related mainly to real income generation both at present and in future. Another characteristic of material wealth is that it is produced by human effort. In this form of wealth, therefore, we include the stock of capital, infrastructure, commodities produced earlier and of course the real national income currently produced. The stock of material wealth is important as it determines a nation’s purchasing and borrowing power in a globalized world.

The public and private infrastructure is the most visible form of material wealth. This includes: (1) infrastructure for transport of water from various sources for human and industrial consumption, as well as effluent or recycling facilities, (2) capacity to generate energy such as hydro, thermal, solar, wind and nuclear, (3) means of transportation such as highways and railroads, sea ports and air ports, (4) communication devices (accessibility and bandwidth of land and mobile phones, facsimile, radio, television, etc.), (5) housing, business parks and industrial estates, and (6) provision of social services (health, education, banking, etc. at both basic and advanced level).

A country with high levels of material wealth and high levels of spending can boost its own economy as well as others' by promoting consumerism. Interestingly, such nations also appear have a high borrowing capacity, which further fuels the economy in short to medium term. This may however, 'burn out' other types of wealth, detrimental in the long run.

The two sources of finance (internal and external) must be balanced with respect to the two sinks: purchase of products for immediate consumption and investment toward manufacturing activities leading to future wealth generation. Use of internal resources for immediate consumption is a fast and short-term catalyst for accelerating the economy, but it works differently in countries with consumerist and saving attitudes. Guiding the investment of internal resources for future wealth generation processes, such as manufacturing facilities along with the necessary infrastructure and support structure, must be the top priority of every Government. In contrast, external borrowing for immediate consumption on avoidable products that do not contribute to creation of any type of wealth should be resisted.

1.2.2. Natural wealth

The natural resources are those resources available to a nation by virtue of its geographical location, and can contribute to creation of wealth of one or more types. Natural resources, primarily, include materials and energy. Examples of natural material resources include soil (fertility), forests (wood, flowers, herbs, etc.) and minerals (ferrous and non-ferrous metals, ceramics, precious stones, natural polymers and composites). Natural energy sources include water and sunlight, besides coke, coal, crude oil, natural gas and nuclear fuel. Some resources may take both forms. For example, water is an input for farming and manufacturing activities, as well as a source of energy (from potential or kinetic, to electricity).

To the above list, we must add natural climate as a resource. A climate with an average temperature and humidity close to human comfort levels promotes various activities for creation of other forms of wealth. It also minimizes the expenditure of various resources to create an artificial climate in isolated enclosures conducive to habitation or work.

Waterways (rivers), long coastline for seaports and a terrain suitable for laying highways and railroads also add to the natural wealth, by bringing down the cost of transportation of people, raw materials and finished products.

1.2.3 Intellectual wealth

Intellectual capital refers to the collection of innovative ideas that can potentially lead to creation of wealth. Ideas are primarily generated by people. Three factors affecting the intellectual capital of a nation are: (1) the number of innovative people, (2) their efficacy and efficiency for idea-generation, and (3) the mechanism for storing and exchanging innovative ideas.

The number of innovative people depends on four factors: the system of education and training (internal sources), their absorption or employment in other activities (internal sinks), their movement to other nations or 'brain-drain' (external sinks), and the influx of innovative people (external sources). The movement can be temporary visits or long-term immigration.

The efficacy of innovative people implies the quality of ideas, whereas efficiency implies the quantity or number of ideas. Both are important. They are influenced by the working environment (freedom to think and minimal noise/disturbance of all types), networking (for constructive criticism and cross-fertilization of ideas) and motivation (financial incentives as well as social recognition).

At present, the mechanism for storing and exchanging innovative ideas is primarily provided by the legal framework for intellectual property rights (IPR), including patents, copyrights and trademarks. By obtaining a patent or copyright, the innovator or author is assured the right to commercialize and profit from his work (by own self or by granting the license to others) for a reasonable period. This also ensures that limited resources are not spent for 'reinventing the wheel'; a patented idea work may trigger other ideas; and the idea is not lost to humanity with the demise of the innovator. It can be seen (Table 1.4) that there is a sharp inequality between the patents filed and granted across the developed and developing countries. The future distribution of income will be greatly influenced by patenting and hence, there is an urgent need for developing countries to set up institutional mechanisms to deal with this recent phenomenon.

Related issues are the enforcement and social acceptance of the IPR framework, within a country as well as across countries. This has to be at all three levels: Government level (formulating appropriate IPR laws and ensuring their enforcement), manufacturer's level (honoring the IPR laws and regulations) and user level (purchase of products and services conforming to IPR laws).

Table 1.4: Patents filed and granted in selected countries in 1998

Country	*Patent Applications*			*Patents granted*		
	Residents	*Non-residents*	*Total*	*Residents*	*Non-residents*	*Total*
Japan	360338	77037	437375	125704	15744	141448
USA	141342	121445	262787	80292	67228	147520
Germany	67790	134981	202771	19271	32414	51685
Korea	50714	71036	121750	35900	16990	52890
China	14004	68285	82289	1653	3082	4735
India	2111	7997	10108	592	1119	1711

Source: World Intellectual Property Organization, http://www.wipo.int/ipstats/en

The social acceptance of IPR laws is greatly influenced by the level of education as well as the value to end-user. Many people are simply ignorant of IPR laws. Secondly, a product or service should not be priced without due consideration to the need, number and average purchasing power of end-users within a region. A high ratio of price to value generally leads to potential violation of IPR laws.

1.2.4 Cultural wealth

The cultural wealth refers to the traditions (processes) as well as the output (products) of cultural activities over several generations.

Cultural traditions define the roles of people based on their characteristics such as age, gender and family of birth. They also define the relationships among family, friends and colleagues, as well as attitude towards others.

Cultural activities such as art, craft and architecture lead to products. Arts include fine arts (such as painting and sculpture) and performing arts (such as music, dance, plays and movies). Crafts are meant for producing exclusive or custom made products or decorations for products. Architecture deals with creation of enclosures and monuments for habitation, work, education, healthcare, social and religious purposes. The ‘manufacture’ of cultural products is becoming an important part of the economy.

The cultural traditions and activities directly influence the physical, mental and social characteristics of the people, at individual, group and national level. Mental and social characteristics such as innovation-ability, perseverance, leadership, teamwork, competitiveness, risk-taking, ethics and respect for others, directly affect the capability to generate and sustain all types of wealth. These characteristics are continuously shaped by education, training and interaction with other cultures.

As discussed above, the total wealth of a nation does not include only the material wealth, but also natural, intellectual and cultural wealth. A few countries including India are blessed with all types of wealth. It is important to realize their contribution to manufacturing activities in order to create a positive cycle leading to further creation of wealth of all types. This is further explored next.

1.3 Role in wealth creation

There are three strong reasons for all nations to ensure a healthy manufacturing industry. First: the industry provides an array of products to end-users, fulfilling their basic needs necessary for survival and providing comforts and luxuries necessary for improving the standard of living. If a country does not produce certain products, it will have to import them from others that do.

Secondly, manufacturing is a force multiplier: it can create productive employment for the labor force. It also promotes growth of agricultural and services sectors: by creating demand for their products and services, and thereby creating even more jobs, leading to further generation of wealth.

Third, manufacturing is of strategic importance to any nation, especially those aspiring to be leaders. They can and should focus on all sectors of manufacturing. This helps in building up self-sufficiency, as well as overall development necessary for anticipating and catching future technological waves, which could emerge in unforeseen areas. Countries with fewer resources can focus on a limited number of high value sectors, and trade them for other products and services with other countries.

Thus manufacturing activities fulfill physical needs of end-users, create employment, build up strategic competence and generate surplus wealth through exports for future development. Manufacturing has been the engine of growth for all major nations including USA, Japan and Germany. China and Korea clearly staked their development on the manufacturing sector, which was encouraged to grow at over 10% per year, compared to about 5% for India. In 1980 the ratio of China's GDP to India's was less than 1, in 1990 it crossed 1, and by 2000 it exceeded 2. The growth of manufacturing also greatly contributed to improved standards of living; the penetration of consumer goods such as televisions, washing machines and air conditioners is today 5-20 times higher in China than that in India.

At present, according to the World Bank, the total value added in manufacturing activities worldwide is over US$ 5 trillion, accounting for 22% of the world economy.

Let us also examine the relation between manufacturing and other types of wealth.

As manufacturing activities become more and more efficient – owing to competition and scientific research – these consume less raw material (giving high yield) and energy per product. Designers are constantly shrinking the size of products through shape optimization and miniaturization techniques, which further reduce material consumption. Reuse, refurbishment, replacement, replenishment and recycling techniques, along with development of eco-friendly materials and processes will gradually reduce the negative impact on nature.

Unfortunately, the rapid pace of commercial innovation (in which products are designed to become obsolete in a very short period, often within weeks) not only bewilders end-users – who have to learn how to use a new device all over again – but also offsets the above gains. Fortunately, end-users are now demanding nature-friendly products, and forcing manufacturers to take the products back after their useful life. This will push manufacturers to accumulate minor innovations into longer-lasting products, use recyclable materials and adopt nature-friendly manufacturing techniques.

The intellectual stimulation of conceptualizing and creating a new product to fulfill the needs of fellow human beings is supreme. This is fuelled by the competitive spirit to make more products, and make them better, faster and cheaper. These are often achieved by establishing and funding academic and research organizations, which trigger new ideas and create more entrepreneurs. The chain reaction rapidly builds up the intellectual wealth of a nation.

Only a few hundred years back (and even now in many developing countries), a family spent all the time ‘manufacturing’ its own food, clothing, shelter and tools. The large-scale manufacture of products has helped in fulfilling virtually every physical need of humans. This gives the people of developed nations potentially more leisure time for cultural activities. Secondly, the financial wealth gained by manufacturing activities and export gives a higher purchasing power. This implies that people of developed nations need to work fewer hours than those in developing nations for purchasing the same products. However, the perceived need for more products (including luxury items) and social pressures, drive most people to spend the hard-saved leisure time also at work for earning more. This vicious cycle can be broken only by realizing that the total wealth comprises not only material, but also natural, intellectual and cultural wealth, as mentioned earlier.

In summary, manufacturing can be defined as the set of activities leading to and including the transformation of materials into physical products needed by end-users or intermediaries using productivity-enhancing tools, machines and methods. In contrast, service activities do not include physical transformation of materials, but are essential for supporting manufacturing activities. Manufacturing and wealth need to be seen and defined in their entirety. We see that there is a strong two-way relation between the two. A positive cycle will lead to gradual strengthening of both manufacturing activities and wealth of a nation. India is blessed with natural, intellectual and cultural wealth; these need to be properly harnessed to develop a responsible and sustainable manufacturing industry that becomes a role model for the rest of the world.

2 HISTORY AND GEOGRAPHY OF MANUFACTURING

In this section, we will briefly review the evolution of manufacturing industry in different parts of the world. The three waves of industrial revolution in the Western world are described first, followed by a closer focus on the growth of major sectors in specific locations. We will then turn our attention to the Indian manufacturing industry, starting from the ancient and ending with the recent decade. The chapter will conclude with a brief comparative evaluation of India in terms of the manufacturing strategy and status.

2.1 Evolution of manufacturing

The industrial revolution in different parts of the world can be visualized as waves, as first proposed by Nikolai Kondratieff, a Russian economist in 1920s. The first wave started in 18^{th} century England with inventions related to the textile industry, steam engine and printing. The second wave started in 19^{th} century America and comprised of rapid developments related to automobile, railroad and telephones. The third wave in 20^{th} century was led by Japan, which focused on electronics and automation.

Each wave started in a country that already had an environment ripe for that wave, including physical, intellectual and economic resources and a social need or willingness to exploit the results. Each wave produced a host of new products and services. These first catered to the local need, but soon were produced in surplus and exported to other countries. There was a rapid growth in the number and size of manufacturing and service firms. The standard of living of people directly and even indirectly engaged with such firms improved. This in turn led to immigration of people from rural areas as well as from less developed countries. The three needs - appropriate manpower, quality of products and efficiency of production - led to the growth of universities and research laboratories, most of them located close to the centers of manufacturing or related trading activities.

Let us look closely at the three waves of industrial revolution, especially the conditions and catalysts existing at that time, and their impact on the wealth and social changes in the countries involved.

2.1.1 First wave

The most influential transformation of human culture in the Western civilization, since the advent of agriculture, was the industrial revolution of 18^{th} century Europe. It had far-reaching influence on production, consumption, labor, family and social structures. It started in Great Britain, which at that time was the biggest and wealthiest nation and later spread to Germany, France and America.

The most immediate change was that goods that had traditionally been made in the home or in small workshops began to be manufactured in the factory. Productivity and technical efficiency grew dramatically, in part through the systematic application of scientific and practical knowledge to the manufacturing process. Efficiency was also enhanced when large groups of business enterprises were located within a limited area. This led to the growth of cities as people moved from rural areas into urban communities in search of work.

The earliest inventions were limited to cotton weaving, including the spinning jenny, water-powered frame, spinning mule, power loom and cotton gin; all helped the manufacture of cotton goods by speeding up the process. Then steam power was discovered and new fuels such as coal and petroleum were used. This revolutionized many industries including textiles and manufacturing. *Subsistence* economy shifted to the *surplus* economy. Mass production made usually expensive items, such as shoes, less expensive and easily affordable by lower class and less wealthy people.

England led this industrial revolution because the social, political, and legal conditions were favorable to change. Property rights, such as those for patents on mechanical improvements, were well established. There was a predictable and stable rule of law, which meant that monarchs and aristocrats were less likely to arbitrarily seize earnings or impose taxes than they were in many other countries. In addition, a relatively hands-off economic policy permitted fresh methods and ideas to flourish with little interference or regulation. Moreover, England monopolized the trade with America — one-half of all British exports went to America in the 1780's — and later with India.

2.1.2 Second wave

While the first industrial revolution shifted manufacturing activities from workshops to factories, the second industrial revolution involved speeding up the production and reaching the products quickly to end users. Major developments in manufacturing included special-purpose machines and continuous manufacturing, to produce larger numbers of interchangeable parts for assembly into finished goods. The Bessemer and open-hearth processes for steel production and Henry Ford's moving assembly line epitomized the revolution. Transportation and communication systems were the other major thrust areas, which helped connecting resources, markets and people. Large firms, spread across various geographical areas, started operating in various economic activities, giving birth to corporations. Industrial engineers started investigating the most efficient ways to lay a factory, move materials, route jobs, and control work through precise scheduling.

America emerged as the leader of this wave. The population was highly literate and the country was able to attract knowledgeable and ambitious individuals from Europe by offering monetary rewards. This included Samuel Slater from Britain – who established the first successful textile mill, and is hailed as the father of the American Industrial Revolution; and Du Pont from France – who established the first successful chemicals company that today employs nearly 80,000 people and has revenues of over US$20 billion. The American government invested heavily in laying transportation and communication networks. The similarity of language, culture, legal and political system with Britain, and a system that encouraged enterprise, helped in producing innovative ideas and their free exchange.

2.1.3 Third wave

The electronics industry characterized the third industrial revolution. It originated in Europe and America but was gradually taken over by an Asian country: Japan.

While the foundation of previous revolutions was in materials, resources and manpower, the electronics industry relied on intellect and knowledge base. These were universal, mobile and less susceptible to monopoly controls and political restrictions. The Japanese electronics industry started producing (music) organs, watches, calculators, numerical control for machine tools, robots and electronics components used in various types of equipments, followed by computers, communication equipment, office machines and semiconductors. By mid-1970s, their output was second only to United States.

It is interesting to note that in 1967, the first industrial robot was imported into Japan from the United States. A year later, Japan's first industrial robot was developed. Within just 12 years (by 1980), Japanese industry was employing around 70 percent of world's total robot population in factories.

Three factors provided the foundation for Japanese success: manufacturing strategy, flexible organizational structure and government-industry cooperation.

One of the biggest factors of success was the product market chosen by the Japanese industries. They focused on consumer goods market (rather than on the military applications) which is highly competitive. Competition resulted in continuous innovation and Japanese firms had to increase their R&D expenditure to keep up with the latest technological development. However, with the accumulation of basic knowledge and the constant effort to catch up with the latest technologies, the emphasis began to shift from market-driven to technology-driven innovation. This successful transformation enabled Japan to obtain world leadership in the field of electronics and automation.

Flexible organizational structure on Japanese firms was another major reason of Japanese leadership. The R&D organizational structure, which came into existence, shows how quickly Japanese could respond to change. As the demand for innovativeness increased, the layer of research activities was increased from one to three steps: (1) basic research in the central research institutes; (2) applied research for both technological development and commercial product development in the technical center outside the division (but inside the division group); and (3) immediate technological and commercial research within the division. To keep researchers away from the hassles of bureaucratic organizations, task forces and outside ventures were created and used.

The cooperation between corporations, and the coordination between them and the government also played a major role. It reduced uncertainty, by eliminating unnecessary competition, by providing protection and by stimulating research activities. In the initial phase, government research institutes took the initiative in promoting research activities, and helped corporate researchers by providing information, grants, and targets. When it came to the second phase, the government began to pursue the two policies of protection and promotion of research activities. In the third phase, the policies of liberalization of some industries were added in order to cope with trade pressures from the US, but the protection and promotion policies remained the same.

2.2 Growth of major sectors

The location and growth of major manufacturing sectors is governed by several factors. The traditional factors include the proximity to raw materials, water, energy sources, labor force and customers. These are becoming less important because of their easier availability and mobility. Other factors that are becoming more important include proximity to ancillary industry, educational institutes, technology parks and transportation routes or hubs (including highways, railroads, sea ports and air ports). The preference of investors and government incentives to develop a particular region, as well as real estate prices, climate and cultural life also influence the location. Once a critical number of manufacturing firms come up, it usually becomes a preferred location for new firms, owing to the availability of various resources already ‘tuned’ to the range of products being manufactured. This leads to manufacturing clusters, some of which are studied in the following sections.

2.2.1 Metal and automobile

Iron, steel and aluminum are the major metals required for industrial machinery, transport equipment (farming, automobiles, railroad and ships) and construction. Indeed, the production of metals continues to be a good indicator of economic activity.

Pittsburgh

The availability of iron ore, coke and limestone, transportation facilities (earlier water, later railroad) and immigrant labor led to the rapid growth of Pittsburgh in USA as the iron and steel capital of the world by the turn of the 19^{th} century. By that time, there were 11 large steel plants in Pittsburgh producing 15 millions tons of ingot steel; about half of national production. By that time, America was producing half of worldwide steel production. Andrew Carnegie and Charles M. Schwab built their steel-based fortunes in Pittsburgh. Soon, other industrialists such as Westinghouse and bankers such as Thomas Mellon joined their ranks. They in turn promoted other industries, including glass, aluminum (Alcoa is the world largest producer of aluminum today) and Heinz (famous for bottled pickles and ketchups). They funded the Carnegie Mellon University and other institutions. The streams of immigrants from different parts of the world converged to produce a rich culture, including art, cuisine and traditions. By 1950, Pittsburgh had over 600,000 residents and so much smoke that street lights were kept burning during daytime and businessmen changed their shirts at noon. After the Second World War, the political and business leaders of the city joined forces to pull down the old structures and rebuild a new city. Today the city is known more for its high tech enterprises, including robotics, computers and biotechnology than for steel.

While iron making has a long history, the production of steel in the Western world is more recent. Steel-making methods were primarily developed in Europe: Bessemer process (UK, 1860), followed by Martin or open-hearth process (France) and Linz-Donawitz or LD process in Austria (1950). The technology rapidly spread to America and later to Japan. The current production of steel in European Union is about $60 billion, followed by Japan ($14 billion) and USA ($6 billion).

The two major internal combustion engines were also first developed in Europe, by Germans: Nikolaus August Otto (1867) and Rudolph Diesel (1892). These effectively replaced stream engines. Earliest automobile manufacturers in Europe include: Volkswagen, Daimler-Benz (now Daimler-Chrysler) and Opel (a subsidiary of General Motors) from Germany; Renault and Citroen from France; Fiat from Italy and Volvo from Sweden.

The mass production methods pioneered by Henry Ford, particularly the moving assembly line introduced in the Detroit plant dramatically reduced the price of the T-Ford car from $950 in 1909 to $295 in 1922, and made it affordable to the masses. The Detroit area, earlier famous for manufacture of wagons and boats (equipped with internal combustion engines) soon emerged as the automobile capital of the world. The Big Three: General Motors, Ford and Chrysler, which accounted for over 90% of American car production, started their production in Detroit and still have their headquarters there.

The Japanese and Korean automobile industry shot into prominence only after the Second World War, and is dominated by Toyota, Honda, Mitsubishi, Mazda and Suzuki of Japan and Hyundai of Korea.

At present, the European Union continues to lead in the total production of automobiles ($270 billion), followed by USA+Canada ($120 billion) and Japan ($80 billion).

2.2.2 Textile and paper

Until about the turn of 18th century, textile was a domestic industry based entirely on human labor, especially for the spinning of yarn, one thread at a time using the spinning wheel. A series of mechanical innovations in Britain brought down the cost dramatically. Samuel Crompton's the mule developed in 1779 produced quantities of fine, strong yarn. Other machines printed patterns on the surface of cotton or linen by means of rollers. In 1894, Northrup produced an automatic loom. Soon, cotton yard could be produced so cheaply in British factories that it displaced hand spun yard even in countries like India where the wages of workers were one sixth of those in Britain. The USA imposed protective tariffs against British imports to protect its domestic spinning industry. Gradually, the technology spread to other countries. Today China, United States, India and Pakistan together account for more than 50% of the production of textiles in the world. The British mills in Manchester and Lancashire closed down in 1970s. The total value of annual textile production is estimated to be over $100 billion.

Paper has been a major driver for development, providing the means for people to record and communicate ideas, news and works of art. It is said to have been invented in China in 105 A.D. Much later, in 751 AD. it was picked up by the invading Arab armies. The first paper mill in Europe was built by the Arabs in Xativa, Spain. Slowly it spread to other countries in Europe. By 1867, the technique of making fine quality paper from wood was perfected. By 1900, economical and mass produced paper became a reality. Today North America and Europe account for more than 60% of world paper production but their share is gradually decreasing. Latin America's and Asia's share has increased over the years due to cheaper labor and growing demand.

2.2.3 Petroleum and chemical

Although the combustible properties of oil had been known since ancient times, its collection was limited to sites where the oil naturally and slowly percolated to the surface. In 1859, Edwin L. Drake drilled the first successful oil well 69 feet deep near Titusville in northwestern Pennsylvania in America. The discovery triggered the 'oil rush' as fortune seekers rushed to the site to buy land and construct oil derricks. Subsequently, new oil fields were discovered in Texas, California and Louisiana. By 1879, John Davison Rockefeller and the Standard Oil Company controlled 90% of the refining capacity in the United States. Until about 1910, the United States was producing 60-70% of world's oil. The Standard Oil Company monopoly was broken by the Anti-trust Action in 1911 to form Chevron, Mobil, Exxon and Amoco as separate corporate entities

Elsewhere, oil was discovered in Iran in 1904, which led to the birth of British Petroleum. At the beginning of the 20th century, the Royal Dutch Shell Oil Company was formed. The company embarked on an aggressive expansion into Venezuela and Mexico. The industry continued to grow as new old fields were discovered all over the world. The Middle East, Venezuela, Indonesia, Russia and the United States combined together have more than 90% of proven oil reserves in the world. After the outbreak of the World War I, the demand for oil in both factories and on battlefield skyrocketed.

In 1850, Great Britain was the largest producer of chemicals. The German and U.S. chemical industries subsequently grew much faster than the British. German growth was fueled to a considerable extent by developing new chemical technologies. Until around 1930, US developed her own chemical industry largely by importing European chemical technologies and adapting to the American context.

In the late 19th and early 20th century, Germany was the home of the finest university chemistry programs, the Kaiser Wilhelm (later Max Planck) Institutes and the most advanced scientific journals in chemistry. Germany by 1913 possessed the largest chemical industry in the world and was also the largest exporter with a 40.2% global share. With the rapid development of the American chemical industry in the first half of the 20th century, the Japanese chemical industry in the second half of the 20th century, and more recently the growth of East Asian economies, the British and German share of world production and exports have decreased substantially since World War I.

Still, Germany at the turn of the 21st century continues to be the second largest chemical exporter in the world after the United States. This has helped maintain European Union's leading position in production of chemicals ($310 billion), followed by USA ($82 billion) and Japan ($30 billion).

2.2.4 Computer and communication

Computer and communication technologies have affected every sector, directly or indirectly in the last two decades. The introduction of personal computers and growth of telecommunications in early 1980s triggered a revolution. By 1990, personal computers began entering homes. Soon, microprocessors were being embedded in many other tools and products also, such as cars and washing machines. The IBM quickly rose to become a Fortune 500 company and maintains a high position with over $80 billion revenues per year, followed by Hewlett-Packard, Dell Computer and Sun Microsystems. Microsoft, which started off by supplying the critical operating system for the computers quickly built a huge and growing business worth over $25 billion per year.

Computer technology started assisting businesses in a variety of ways: computerized inventory management, computer-driven manufacturing, Enterprise Resource Planning (ERP) software and database management systems, all became well-accepted terms of business. This situation gave rise to another kind of giants in the economy; these were the software companies like Microsoft, Oracle and SAP who gave birth to the knowledge economy.

As soon as the AT&T's Bell Labs was split up into seven independent companies, Ameritech, US WEST, NYNEX, Pacific Telesis, Southwestern Bell, Bell South and Bell Atlantic, companies like MCI and Sprint raced to build fiber-optic networks across the USA. The network connected the users to virtually anywhere in the world through the use of copper, coaxial or fiber cable. By the early 1990s, these companies shifted from moving voice to moving data, giving rise to the Internet. These companies continue to command a huge business; for example, the annual revenues of AT&T and Verizon Communications in USA are exceed $110 billion, and Deutsche Telekom based in Germany earns $ 43 billion per year. New firms such as AOL Time Warner married content with Internet, and have revenues touching $40 billion per year.

Table 2.1: Growth of Internet

Year	*Major Breakthrough in the Internet*
1962	Packet-switching (PS) networks developed
1971	People communicate over a network, email invented
1977	E-mail takes off, Internet becomes a reality, number of hosts over 100
1984	Number of hosts exceeds 1,000. Domain Name Server (DNS) introduced
1987	Commercialization of Internet, number of hosts 28,000
1991	World-Wide Web (WWW) released by CERN (Tim Berners-Lee)
1993	WWW revolution: number of hosts 2 million. Over 600 WWW sites
1995	Netscape launches a graphical browser for Internet
2002	Over 580 million users of Internet worldwide

Source: History of the Internet, http://www.netvalley.com

With the growth of Internet, computers and communications became inextricably linked, each feeding the phenomenal growth of the other. Each and every thing of the old economy had a new meaning now. From Barnes & Nobles to Amazon, Disney to AOL Time Warner, and US Mail to Hotmail, old monopolies were giving way to new monopolies of the networked world. Not only the web version of the offline business models emerged, a number of new companies, like Ebay that relies on the network effect of the new economy, and Google – a search engine, got shaped.

New technologies have an impact much bigger than what literally takes place online. American businesses began the process of reengineering, downsizing and outsourcing. Taking the advantage of new information technologies, they initiated to create the smaller, more versatile economic units of the coming era.

On the most obvious level, hardware and infrastructure companies experienced exponential growth, as building the new information network became one of the great global business opportunities around the turn of the century. CISCO, SUN and IBM were the enablers of the networked economy.

Simply put, fiber to the home, college and business became an essential infrastructure for economic development in the Information Age of the twenty-first century just as railroads were in the last century, and highways were in this century. As the economy shifted from agrarian-based to industrial-based, the ability to move goods via railroad first, and highway later proved essential. Now we are shifting toward a service-based economy in which the ability to transport information is proving essential.

2.3 Indian manufacturing industry

Indian science and technology, as well as manufacturing and trade, has an interesting history that has been poorly documented. Here we piece together a brief description about ancient, medieval and post-Independence India from various sources.

2.3.1 Ancient India

India has a rich heritage of wisdom and knowledge embodied in *Vedas*, *Upavedas, Vedangas* and *Upanishads*. The word *Veda* implies the fountainhead of knowledge, required by mankind for spiritual as well as temporal (worldly) requirements. This was realized by (or revealed to) sages through observation, study and meditation of the physical world around them. Indeed, *Vigyana* implies insight or perception with freedom of thought. There are four *Vedas*: *Rigveda, Samaveda, Yajurveda* and *Atharvaveda*, claimed by scholars to be in existence 25,000 to 10,000 years B.C. The *Upavedas* are derived from *Vedas* and describe sciences, arts and engineering. These include: *Arthaveda* for economics and statecraft; *Ayurveda* for medicine and health; *Dhanurveda* for military science; *Gandharvaveda* for music and the arts; and *Sthapatyaveda* for architecture and engineering. The *Sthapatyaveda* contains the principles of realizing all kinds of man-made structures, and is derived from *Atharvaveda*. The *Vedangas*, meaning the limbs of *Veda*, enumerate the laws, codes and rituals for grammar, astronomy, righteous living, etc. A few works of sage-scientists are listed in table 2.2.

The earliest evidence of manufacturing activities in Indian subcontinent is found in the remains of the Harappan civilization (about 3000 BC). Accurate weights and measures were in use. Kilns for smelting copper ingots and casting tools were in existence. Metal tools included circular saws, pierced needles and bronze drills with twisted grooves. Technologies for lifting, loading and transportation of construction materials, building construction ramps, scaffolding, and related tools were used for creating monumental architecture. Ports such as Lothal in Gujarat were developed as export centers of early manufactured products from smelted copper and bronze.

Table 2.2: A few scientific works of ancient India

Sage	*Date*	*Work*	*Subject*
Kapil	3000 BC	Sankhya philosophy	Cosmology and psychology
Bharadwaj	800 BC	Vimana shastra, Yantra Sarvasva	Aviation and space sciences
Atreya	700 BC	Charak Samhita	Ayurvedic medicine
Kanad	600 BC		Atomic theory
Panini	600 BC	Astadhyayi	Grammar
Sushrut	450 BC	Sushrut Samhita	Anesthesia, plastic surgery
Dhanwantari	400 BC		Surgery
Kautilya	400 BC	Arthashastra	Economics
Parashara	100 BC		Botany
Nagarjuna	50 BC	Ras Ratnakar	Chemistry and metallurgy
Aryabhatt	500 AD	Shulva Sutra	Astronomy, mathematics
Varahamihr	550 AD	Panschasiddhant, Bruhad Samhita, Bruhad Jatak	Geography, constellation science, animal science
Brahmagupta	630 AD	Sputasiddhant	Astronomy, progressions
Sridharacharya	1000 AD		Quadratic equation
Bhaskaracharya	1150 AD	Lilavati, Bijaganita, Siddhantshiromani, Surya Siddhant	Algebra, arithmetic, geometry, mathematical techniques, gravity

Source: Compiled from various resources on the web

Kautilya's *Arthashastra* written around 300 BC, mentions the processes for metal extraction and alloying. Later Sanskrit texts talk about assessing and achieving metal purity. The *Rasvatnakar* written by Nagarjuna in 50 BC mentions the distillation of Zinc in Zawar, Rajasthan, and excavations by the M.S. University of Vadodara verify the existence of kilns used in the distillation of the metal.

The trade was well organized and supervised by the local heads of the city. There were numerous guilds like carpenters, smiths, leather workers, painters etc, under the leadership of a president. There is enough evidence to show the corporate commercial activity and partnerships in trade. There was very little government control of business. The industrial centers were connected by good roads, which greatly facilitated traffic. Alexander's records provide accurate information about a road that ran from Penkelaotis (Pushkalavati) near the modern Attock and passed through Takshila to Patalipura (Patna) after crossing the river Bias. Another road joined

Pushkalavathi and Indraprastha (Delhi) and after connecting Ujjayini (Ujjain) descended down the Vindhya range, went into the Deccan through Pratisthana after crossing the Narmada and the Tapti rivers.

Greek literature indicates that Indian exports included a variety of spices, aromatics, quality textiles (muslins and cottons), ivory, high quality iron and gems, which were in high demand. In return, Rome supplied cut-gems, coral, wine, perfumes, papyrus, copper, tin and lead ingots to India. The trade balance was however, in India's favor, and the net payment was over fifty million *sesterces* per year in the form of gold or silver coinage, according to Pliny.

2.3.2 Medieval India

There were several scholar-rulers who actively supported science and technology through grants from royal treasury. An example is Raja Bhoja (1018-60) of Dhar-Malwa, well educated in sciences and arts, and a great engineer. He was the architect of Bhojsagar, one of the largest artificial irrigation lakes of medieval India, started a university called *Bhoj Shala*, and provided a detailed network of roads connecting villages and towns in his magnum opus, *Somarangana Sutradhara*.

Table 2.3: Milestones in Indian iron and steel industry

Period	*Milestones*
300 BC	Porus presented Alexander 30 lbs of Indian iron. Kautilya (Chanakya) writes about minerals, including iron ores, and the art of extracting metals in 'Arthshastra'.
350 AD	A 8-metre wrought iron pillar erected near Delhi in memory of Chandragupta II. Another 16-metre iron pillar erected at Dhar (near Indore).
13th century	Massive iron beams used in the construction of the Sun temple, Konark
16th century	Indian steel known as 'Wootz' exported to Middle East and Europe
17th century	Manufacture of cannons, firearms and swords and agricultural implements. Suspension bridge built over Beas at Saugor with iron from Tendulkhma (MP). Iron smelter built at Porto Nova (Madras).
1870	Bengal Iron works established at Kulti.

Source: SAIL India, www.sail.co.in

The Iron Pillar of Delhi, which stands 23 feet, made of wrought iron with iron content of 99.72%, without showing any signs of rust is a remarkable example of the level of metallurgical science in ancient India. By middle ages, India was producing very high quality steel and was also able to extract zinc from its ore. Various alloying techniques were in use. Abul Fazl in *Aini Akbari* mentions the coating of copper vessels with tin. *Bidari*, an alloy of copper, lead and tin developed in the Deccan, was extensively used. Several writers, such as Dharmapal, have mentioned the quality and cost competitiveness of Indian foundry and forge industry. Captain Presgrave of the Sagar Mint wrote in his report after he wrought up the iron into bars and rods for an iron suspension bridge on which he was employed, that the "bar iron (is) of most excellent quality, possessing all the desirable properties of malleability, ductility at different temperatures and of tenacity for all of which I think it cannot be surpassed by the best Swedish iron".

Several texts mention water-management techniques, light and airy clothes, and food preserving techniques in Medieval India. Cotton goods industries emerged as the biggest employer after agriculture. By 1700, India was the highest exporter of textile in the world. The "perfection of the manufacturer" and the "simplicity of the tools" fascinated all the visitors to the subcontinent. It was said that "on the coast of Coromandel and in the province of Bengal, when at some distance from the high road or a principal town, it is difficult to find a village in which every man, woman and child is not employed in making a piece of cloth."

In spite of all these developments in ancient and medieval India, it totally missed the Industrial Revolution that was taking place in Europe. Indian life was initially easy and prosperous because of mild weather and huge trade surplus. Education in *Gurukuls* and *Madrasas* became orthodox and resisted change. After British colonization, education for the masses became scant, there was no freedom for innovation, and Indian industries were dragged into an age of ignorance. On the other hand, life in Europe was hard in long and harsh winters, and the banks were bearing a huge trade burden. The education got liberated from the orthodox clutches of Church, leading to a more innovative and scientific society driven by the local needs.

2.3.3 Post-Independence

At the time of independence in 1947, India was primarily an agrarian economy with little industrial development. There were very few industries confined to a few cities. Export strategy was not conducive to the country's interest as it was seen as a mechanism to transfer raw material to the United Kingdom, so that they can sell finished products to their colonies. The social indicators were poor. The immediate task for the then government was to improve social and material condition and induce rapid growth in a stagnant economy.

Table 2.4: Composition of public sector outlays in various Five Year Plans

Five Year Plan	*Agriculture & Irrigation*	*Power*	*Industry*	*Transport & Communication*	*Other*
First Plan (1951-56)	30.6	13.3	6.1	26.5	23.5
Second Plan (1956-51)	20.7	9.6	23.5	28.3	18.0
Third Plan (1961-66)	20.4	14.6	23.0	24.7	17.4
Fourth Plan (1969-74)	24.0	15.4	22.8	20.4	17.4
Fifth Plan (1974-79)	22.2	18.8	24.3	17.4	17.3
Sixth Plan (1980-85)	23.9	28.1	15.5	16.2	16.3
Seventh Plan(1985-90)	20.4	28.2	13.4	17.4	20.7
Eighth Plan (1992-97)	20.6	26.6	10.8	23.7	18.3
Ninth Plan (1997-2002)	19.4	26.6	8.1	22.2	23.7

India's strategy for industrialization became visible in the Second five-year plan that placed key emphasis on heavy industries (See Table 2.4) and saw a major role of public sector in industrialization. High investment areas like iron and steel, energy, coal, transport, mineral oil, arms and ammunition, came under government control on account of 'lack of private initiative' and 'control strategy'. Infrastructure was a natural responsibility of the State. The Government's role was seen in alleviating inequality of income and wealth and fostering indigenous development of technology. In areas that were left for private enterprises, Government intervention was permitted through fiscal measures, licensing and direct physical allocation. By the mid-seventies it was becoming clear that the licensing system had become more and more regulatory and less and less developmental.

Since the mainstream thrust of industrialization was on capital-intensive heavy industries, the growing demand of consumer goods was to be met by the small-scale industries. Policy instruments for the small sector moved from being promotional in the beginning to more protective at the later stages. Beginning with late sixties, financial incentives and reservation for small sector emerged as a new policy instrument to enable these industries to stand competition from the large industries.

The Third Five Year Plan (1961-66) saw a major thrust on self-reliance through an extreme import substitution strategy. This strategy led to favoring replacement of imports by domestic production anywhere and at whatever cost. Such export pessimism was also popular in other developing and Latin American economies.

The growth of industrial output in India has consistently fallen short of targets laid down in the successive plans. The growth was reasonable during the first three Five Year Plans but for the next three Five Year Plans the industrialization lost direction. It was only in the sixth plan that some progress was achieved and the seventh plan, which marginally missed the targeted growth, showed distinct improvement.

Table 2.5: Growth rates of Indian industrial production (% per annum)

Plan	*Period*	*Target*	*Actual*
First	1951-2 to 1955-6	7.0	7.3
Second	1956-7 to 1960-1	10.5	6.6
Third	1961-2 to 1965-6	11.0	9.0
Fourth	1969-70 to 1973-4	12.0	4.7
Fifth	1974-5 to 1978-9	8.0	5.9
Sixth	1980-1 to 1984-5	8.0	5.9
Seventh	1985-6 to 1989-90	8.7	8.5

Source: Calculated from Various Sources

Though substantial investments were made in the Public sector, its share in the GDP remained around 25% in 1990. The infrastructure requirement for the growing industrialization could never be met. The share of infrastructure in the total public investment declined from almost 40% in the sixties to 34% in seventies. Besides infrastructure, the Public sector was expected to set up capacities in capital goods industries. Though these capacities were set up, they were poorly utilized. The contribution of public sector to gross saving (which is available for investments) was minimal and 1975 onwards it became negative.

In Table 2.6, we provide a synoptic view of the growth of India's manufacturing sector. It can be seen that the manufacturing sector recorded the lowest decadal growth rates in the seventies, especially in the early seventies. Trend growth rate of manufacturing sector during the post-independence period has been 5.7 per cent per annum over almost half a century. Between 1950 and 1980 the overall Indian economy grew sluggishly (less than 4% per annum), but accelerated to nearly 6% per annum thereafter. This performance was a considerable improvement over the nearly stagnant colonial economy discussed above, especially the pre-1930 colonial economy, underlining the positive economic role of a sovereign state. At the same time, however, this growth performance compares rather unfavorably with both South Korea and Brazil analyzed in the following section, forcing one to critically scrutinize the state's role in the Indian economy.

Table 2.6. Profile of growth rates of Indian manufacturing sector

Time Period	*Average Annual Growth Rates*	*Decadal Trend Growth Rates*	*Trend Growth Rate*
1952-54	5.3	7.2	5.7
1955-59	7.4		
1960-64	9.3	5.7	
1965-69	3.9		
1970-74	2.8	4.4	
1975-79	5.3		
1980-84	4.8	7.6	
1985-89	8.9		
1990-94	5.1	7.1	
1995-99	7.9		
2000-01	5.3		
2001-02	2.9		

Trend growth rates have been computed using semi-logarithmic trend equation.

The Tenth Five Year Plan target envisages almost doubling of growth rate of manufacturing sector to 10% per annum. Prior to nineties, the constraints on growth of industrial sector were primarily domestic. The scene seems to have changed considerable in after the eighties.

At the global level, India's contribution to world trade continued to decline, partly, because of export pessimism. In terms of numbers, from 2% in 1950, it declined to 1.1% in 1960 and 0.65% in 1970. India's share of export of manufactured goods declined from 1% in 1960 to 0.64% in 1970 to 0.48% in 1980.

2.3.4 Last decade

Faced with large trade deficits and overvalued currency, Government of India took major steps to liberalize the economy. The new industrial policy, unveiled on July 24th, 1991 aimed at eliminating barriers to entry and removing restrictions of Monopolies and Restrictive Trade Practices Act on the domestic industry to enable it to expand, for facing foreign competition, promoting direct foreign investment, restructuring the public sector and integrating the Indian economy with the global economy. Industrial licensing for all industries, except for few, was abolished. Foreign direct investment ranging from 51% to 100% was allowed depending on the industry.

The process of liberalization brings large decline in output in the early stages. In India also, a similar trend was observed. The manufacturing sector grew by only 0.2% in 1991-93 (immediately after liberalization) and climbed to 14% in 1995-96. It then however, lost steam and fell to 6% in 1997-1998.

At present, the Indian Manufacturing sector is exhibiting a Dual characteristic. While certain sectors like IT, pharmaceutical, automobile and fast moving consumer goods (FMCG) have shown unprecedented growth in the past five years, the core sectors of engineering goods, chemicals and small scale manufacturing, are in even poorer health under global pressure of open economy. The slump coupled with rising competitive pressure is forcing many Indian industries to restructure their operations. Indian industry is in fact witnessing unprecedented consolidations, takeovers, and mergers.

Currently, the Indian manufacturing sector is grappling with the problem of competition from low priced mass consumption goods from Chinese and Asian markets and quality competition from products of advanced economies produced by superior technology. Import liberalization has hit a vast section of the manufacturing sector, though there are a few success stories as well. On export front, the manufacturing sector is not able to compete both due to the fact that our rivals in the global markets have had massive devaluation or depreciation of their local currencies.

2.4 Comparative evaluation

Let us evaluate the current status and direction of the Indian manufacturing industry with respect to the world. We will focus on two aspects: manufacturing strategy and competitiveness.

2.4.1 Manufacturing strategy

In general, various countries have adopted two main strategies of growth of manufacturing sector. First is the import substituting industrialization and second is export led growth. Elements of former and latter can be combined in various proportions to suit the local needs and evolve domestic strategies. India and many countries in Latin America followed the former strategy, wherein, they tried to reduce their dependence on imports by developing and protecting industries related to import-substitution. The prime reasons for adopting this strategy is to reduce the dependence on foreign economies and to alleviate the foreign exchange constraint on import of capital goods. Protection in the form of high import tariffs on goods produced by these industries, making finance available at concessional rates, subsidies, tax holidays, etc. are accorded to import substituting industries. This strategy is suitable for establishing the manufacturing capability and nurturing it in the infant stages of the industry. However, the limited market size coupled with high investments required for manufacturing and R&D facilities restricts the number of manufacturers. Thus, there is little or no competition, both internal and external. This builds up monopolies and complacence, leading to poor quality, high price and low productivity. Eventually, the gap between domestic and 'foreign' products in terms of features, quality and price becomes too large to leap across, even with technology transfer, licensing or branch plants of multi-national companies. This is a characteristic of a closed economy and hardly practicable in an era of dismantling trade and non-trade barriers.

The second strategy, viz., export led growth is characterized by high level of exports in relation to national income. It is a challenging strategy. It requires high sensitivity to the market needs as well as technological developments worldwide, close interface between the academia, industry and government, and high motivation to be world-class. The results are impressive; this strategy yields the fastest growth in terms of employment, income generation and standard of living. Once the standard of living rises beyond a critical point, the motivation plateaus and the manufacturing industry starts giving way to the service sector.

An intermediate strategy initially allows high imports of goods that can be used in export-promotion. The local manufacturing industry is expected to 'catch-up' by reverse engineering the imported products, manufacture equally good products for import-substitution, introduce product and process innovations and eventually start exporting the products. This implies setting the targets for import-substitution in products, which are assembled locally, using imported components. For this strategy to succeed, the local manufacturing industry must be mature enough and have a well-established interface with local academic and research institutions.

A few countries, especially Japan, have followed a mix of the three strategies, emphasizing different strategies at different periods during their development. This implies initiating the local manufacturing industry within a closed economy, followed by import of products and import-substitution manufacturing, and finally focussing on export-based manufacturing. The hybrid strategy is still used for every new wave of technology, where imported products may not be available. In such a case, keen internal competition is encouraged to weed out the weak players; then the top two or three manufacturers enter the world market and reap the benefits of economies of scale.

2.4.2 Competitiveness

Two major sources of information on India's competitive position vis-à-vis the other countries include the World Competitiveness Yearbook and Global Competitiveness Report.

The competitive ranking in World Competitiveness Yearbook is based on four major factors: economic performance (74 criteria), government efficiency (84 criteria), business efficiency (66 criteria) and infrastructure availability (90 criteria). Economic performance is evaluated using various variables pertaining to domestic economy, international trade and investment, employment and prices. Government efficiency is assessed using indicators pertaining to fiscal policy, institutional framework, legislations pertaining to business and education. The relevant variables pertaining to business efficiency come from the domain of productivity, labor market, finance, management practices and the impact of globalization. The definition of infrastructure encompasses not only basic physical, technological, scientific infrastructure and health and environment but also the value system. The USA ranks first; China currently ranks 37th and India ranks 42nd in a group of 49 countries. Countries such as Singapore, Germany and UK are ranked in between. With better functioning of government and infrastructure support (in which India performs poorly), the performance of the Indian economy can be significantly improved.

The Global Competitiveness Report compiles two ranks: the growth competitiveness rank and current competitiveness rank. These are based on technological and communication factors, government effectiveness, macroeconomic environment and stability, credit rating of the country, quality of business environment, etc. The Current Competitiveness Index ranks (of the countries indicated in the Global Competitiveness Report) are listed above. This ranking exercise included 75 countries. India's rank in this report is better (36th; China is 47th) than that reported in the World Competitiveness Yearbook, though there is still a long way to go as regards competition in the global markets is concerned.

In brief, despite a glorious past and availability of all forms of wealth needed to pursue sustainable development, India's competitiveness in manufacturing is extremely low. As we saw, apart from the social and political environment, there were favorable government policies for the Industrial Revolution to take place in Britain, America and Japan. India's development strategy was focused on self-reliance through extreme import substitution. As the world trade increased at an unexpected rate, it led to a minuscule share in world trade. This closed economy model led to uncompetitive Indian industry and the current state of Indian manufacturing sector.

3 FUTURE DRIVERS AND ENABLERS

After a historical perspective of the manufacturing industry in different parts of the world as well as India, let us now turn our attention to the future scenario. We will first study a few major economic and technological drivers, and examine as to how they will influence the products and manufacturing processes. Finally, a few key methodologies, that will become essential to reach as well as maintain the competitive edge, are described.

3.1 Economic drivers

Here we discuss two major economic drivers for future growth of manufacturing sector, especially in the Indian context: Globalization and Intellectual Property Rights.

3.1.1 Globalization and regionalism

Globalization refers to integration of various local/domestic markets into larger/global markets. The process of globalization has enabled ‘sourcing capital where it is cheapest, producing where it is most efficient, and selling where it is most profitable’. The markets could be for products or for factors of production, such as capital, labor or enterprise. The integration of markets takes place basically due to the removal of restrictions, both in terms of price barriers and non-price or quantity barriers. With the emergence of World Trade Organization (WTO), world over, the overall tariff rates (price barriers) are not going to increase. Also, the member countries have agreed to gradually eliminate non-price or quantity barriers. Thus, countries have to compete in global goods market mainly in terms of quality and price.

For example, India has a competitive cost-price advantage in mass consumption goods involving (cheap) labor. It also has an advantage in IT and niche engineering sectors, where it has established quality competitiveness. From this base, it could move up to product differentiation and technologically sophisticated product development to convert the challenges posed by globalization into opportunities.

Among the factors of globalization, capital mobility has become an astonishing development. In the absence of capital mobility, the investment needs had to be financed by export earnings. Now the foreign exchange constraint can be overcome by inviting foreign capital to one’s advantage, provided the rate of return earned on the capital is higher than the interest rate to be paid in case of bond capital and the rate of growth of production in the case of equity capital. Developing countries such as India can take advantage of foreign capital to boost their manufacturing sector.

Another factor is the free mobility of labor across countries. We have witnessed an increasing trend in migration of high-skilled workers from India, especially in IT sector. Given the need for services in industrialized countries, globalization may improve job prospects for migrants from developing countries.

Finally, though the objective of WTO is to establish free and fair trade, there are several escape routes that may be followed by member countries to avert free trade. In fact, environmental standards and social clauses in WTO may just be another way of retaining protectionism. In order to counter that, associations of developing countries with common interest is one of the answers to the covert protectionism – a process that may seem to be antithetical to the process of globalization is that of regionalism. Growing number countries have found it beneficial for various economic and political reasons to integrate themselves. European Union, NAFTA and ASEAN indicate this growing regional integration. In order to compete effectively in the global markets and exert influence in international forums, developing countries need to also take the fact of regionalism rather seriously. Unfortunately, the various hurdles faced in the growth of SAARC has compelled India to look out for participation in other regional associations. Indeed, India needs to combine the strategy of regionalism with freer trade to significantly increase exports.

Along with trade policies, supportive exchange rate policies also are required. China has been able to capture global markets by attaining price competitiveness through massive devaluation of exchange rate along with cost minimization.

3.1.2 Intellectual property rights

As mentioned earlier, intellectual wealth – collection of innovative ideas – is an important part of the total wealth of a nation. The intellectual property rights (IPR) need to be protected and enforced by appropriate laws both inside and outside the country. This enables the creator of an original work to use and profit from his/her work for a certain period of time. In general, this ensures encouragement and reward for creative activities.

The IPRs are of mainly two forms. The first is copyrights for literary and artistic works (books, musical compositions, paintings, sculpture and films) for a minimum period of 50 years after the death of the author. Computer programs and databases also fall under this category. The second is rights for industrial property, including patents and trademarks. Patents are primarily for inventions pertaining to new designs, technologies and trade secrets. Enforcement of patents enables protecting the investments in research and development, and benefiting from the same through technology transfers or licensing mechanisms, usually for a period of 20 years. Trademarks refer to distinctive signs (such as brand names and company logos) that distinguish the goods or services of one firm from those of another. They enable fair competition between firms, and informed choices by customers. Trademarks may last indefinitely, as long as they continue to be distinctive.

We must recognize that the cost of a new drug reflects the huge expenditure on R&D required to arrive at its formulation. Similarly, the material and manufacturing cost of a music CD may be miniscule compared to the creative efforts and labor involved in its composition. Recognition of IPR and its protection across national borders enables the development costs to be amortized over a larger population of buyers, thereby bringing down its price and making it more affordable to customers.

With the globalization of manufacturing, business and trade, the IPRs have become increasingly important and are a constant source of disputes between different countries. One main reason was that different countries had different extent of protection and modes of enforcement of IPRs. To introduce more order and predictability, as well as enable disputes to be settled more systematically, World Trade Organization (WTO) initiated the agreement on trade-related aspects of intellectual property rights (TRIPS). The agreement covers five major areas: (1) how basic principles of the trading system and other international intellectual property agreements should be applied, (2) how to give adequate protection to IPRs, (3) how countries should enforce those rights adequately in their own territories, (4) how to settle disputes on IPRs between members of the WTO, and (5) special transitional arrangements during the period when the new system is being introduced.

Turmeric and Neem

There is a growing tendency by transnational corporations to own and control traditional knowledge. One such area of concern is the healing properties of plants, which are a source of many modern medicines. For example, in 1995, two researchers at the University of Mississippi Medical Centre were granted a US patent on the use of turmeric in wound healing. The Indian Council of Scientific Research (CSIR) took up the case in national interest, and argued that turmeric has been used for thousands of years for healing wounds and therefore its medical use was not novel. They supported their claim through ancient Sanskrit texts and a paper published in 1953 in an Indian medical journal. The US Patents and Trademarks Office upheld the objections and revoked the patent. In another case, the European Patents Office granted a patent in 1994 to an US company for a method for controlling fungi on plants using neem oil. A group of international NGOs and representatives of Indian farmers opposed the patent by presenting evidence that extracts of neem seeds had been known and used for centuries in India to protect crops. The patent was finally revoked in 2000 on the grounds that the patent did not involve an inventive step unknown to the public.

Traditionally, Indians have believed that knowledge cannot be stolen, and that its free distribution leads to multiplication. However, the current global philosophy regarding distribution of knowledge is diametrically opposite, and rewards the innovators by protection of their IPR. The changed reality must be recognized at all levels, and developing countries must be prepared for taking on the challenges associated with the IPRs. This requires a better institutional set up for protecting IPRs and a greater awareness about the issues involved.

3.2 Technological drivers

Here we study the major technological drivers that will influence the future products and processes: (1) Artificial intelligence and awareness, (2) Green materials and (3) Direct manufacturing.

3.2.1 Artificial intelligence and awareness

Artificial Intelligence (AI) is the capability of a non-human device (computer or computer-based system) to perform functions normally associated with human intelligence, such as reasoning and rational judgment. Research in AI started in 1950s at Stanford and MIT in USA, and continues more aggressively than ever before, in universities and research labs all over the world.

The earliest AI applications included expert systems for diagnostics purposes, ranging from medical and oil exploration to hardware repair and manufacturing defects analysis, where Japan quickly took a lead. Other areas of relatively recent success are natural language understanding, speech recognition, machine vision and robotics, besides chess. Some of these capabilities are combined in very recent applications such as intelligent pets.

Sony Aibo

In 1999, Sony Corporation, Japan launched an entertainment robot called AIBO that is capable of interacting and co-existing with people. It is an autonomous robot that acts in response to external stimulation and its own judgment. It can respond to voice commands, express its 'feelings' by lights and sound, act on its own curiosity and gradually expand its capability based on experience. Among its many functions, it can remind its owner of important appointments, make scary noises when someone passes in front, and teach children how to differentiate colors. The latest Aibos can dance to music, and humorously complain if the music is stopped. The robot costing over US$2000 is a huge success in Japan, USA and Europe, with over 100,000 orders for each limited edition of 10,000.

Most meaningful AI applications require a tremendous amount of computing power, in terms of processing speed and memory space. The raw computing power available today in mass produced chips is paving the way for AI devices to penetrate consumer products such as neuro-fuzzy washing machines, voice-activated mobile phones and vision-based house-cleaning robots.

We introduce a new term called artificial awareness (AA) to imply the networking of virtually all devices, so that they can detect the presence of each other and communicate with each other. This has three requirements: (1) an inexpensive way to attach an electronic label to each device (phone, car or washing machine), (2) availability of sufficient number of unique addresses in a standard scheme to cover all devices worldwide, and (3) interconnection of the devices.

If the device already has an electronic chip with memory, then the address can be stored in the chip itself. With chips being put into more and more devices (including toys) and the availability of inexpensive chips from discarded computers, the problem is resolved to a great extent. The mass manufacture of very inexpensive chips for tagging purposes would make it possible for every device to be tagged, just as every item in a supermarket is tagged with a printed bar code.

The current scheme for Internet Protocol (IP) addresses was designed in 1970s and comprises of 32 bits, already insufficient to cover all computers in the world. The new proposed protocol (IP6) will have 128 bits and will be able to address every device worldwide.

Again, at present most of the devices are connected to each other and to the Internet by cables or optic fiber. They may also be connected by wireless means such as infrared or radio waves (for example, the Bluetooth standard) for communication purposes: essentially sending and receiving data.

The Semantic Internet (as proposed by Tim Berners-Lee, the inventor of the World Wide Web) will take artificial awareness to an ever-higher level. Unlike the present Internet, in which the documents do not 'know' their content, in Semantic Internet the documents will use a self-describing language such as XML (eXtended Markup Language) to store their content. This will enable a new generation of automatic programs called intelligent software agents, residing in different devices, to communicate with each other at a higher level.

The computing power in individual devices and their networking with each other will drive manufacturers to create a whole new array of products that will seem to have a life of their own. Today's food processors, washing machines and televisions will appear to be 'dumb' in comparison.

3.2.2 Green materials

Major materials for manufactured products include metals, polymers, ceramics and composites. Metals are divided into ferrous (iron, steel and their alloys) and non-ferrous (aluminum, chromium, copper, lead, magnesium, nickel, tin, titanium, zinc and others). Polymers include thermoplastics (polyethylene, polypropylene, polycarbonate, polyester, polyamides, etc.), thermosets (epoxies, melamines, phenolics, silicones, urethanes, etc.), elastomers (rubber), fibers and natural polymers (wood). Ceramics include carbides, oxides, nitrides and sulfides. Composites are combinations of two or more different types of materials (glass fiber reinforced plastics, ceramic metal matrix composites, etc.).

A typical automobile contains a variety of materials: steel body, aluminum engine block, plastic dashboard, rubber tires, ceramic spark plug and glass windows, to name a few. Ferrous metals contribute over 70% of the weight of a car, followed by non-ferrous metals (10%), the rest being plastics and ceramics. The demand for fuel-efficient vehicles, implying a reduction in weight, is driving the manufacturers towards lighter materials, mainly magnesium alloys, plastics, ceramics and composites. A major thrust in research includes manufacturing techniques suitable for the new materials.
There are two major problems associated with the current approach to the use of materials in manufactured products. The first is the depletion of natural resources by mining and quarrying activities, including extraction of natural gas and oil (used for producing most of the polymers). The second is the dumping of products in landfills at the end of their life. Both activities – mining and dumping – create an imbalance in nature.

One way to address the above problem is to recycle the materials. Metals can be easily melted and mixed with right quantities of other elements to produce alloys of the desired composition and properties, and used in new products. The recycling of plastics and some ceramics poses a challenge that is being addressed. Parts made of composites or a multitude of materials (for example, computer chips) are not easy to recycle, since the separation of constituent materials can be difficult, if not impossible with current technology.

The Matsushita Electric Company

The Matsushita Electric Company of Japan is promoting an aggressive 'green' strategy to maintain its competitive edge. The company was founded in 1918, and today manufactures a wide range of consumer electronic products, home appliances, factory automation equipment, information and communications equipment, mainly under the brand names National and Panasonic. The company has net sales over US$50 billion and over 250,000 employees worldwide. It now recognizes that 'e' not only stands for electronic, but also for ecology and environment. It has opened an eco-technology center called 'jaws' for recycling its consumer electronic products, with a capacity of 1 million units per year. Other manufacturers including Toshiba and JVC are also expected to process their old appliances in this plant. Since metals are more easily recyclable and plastics are not, the number of plastic in a typical Matsushita TV has been reduced from 13 to only 2. Such measures have improved the image of Matsushita as an environment-friendly company.

A more long-term solution is to develop and use nature-friendly or green materials in future products. A green material can be produced from renewable resources and discarded without any long-term negative impact on nature.

The construction and textile industries are pioneering the use of green materials. A recent example is the development of a customized E. coli bacterium at DuPont, USA, to convert corn sugar into propanediol in a fermentation process similar to making wine. Propanediol is used to produce a new family of polymers than can be spun into fibers with a unique combination of softness, comfort-stretch and recovery, vibrant color, resilience and stain resistance.

Many countries are taking steps to promote green materials and green manufacturing. The Japanese Government has passed a "Electric home appliance recycling law" that mandates manufacturers to take responsibility for recycling their home appliances, either by setting up a plant or outsourcing to other plants. The aim is to reduce the waste production to $1/10^{th}$ of current levels. Similar laws are being framed in Europe and America to make the manufacturers responsible for the collection and recycling of old appliances.

3.2.3 Direct manufacturing

At present, a typical product is manufactured by assembling its components, which are in turn manufactured mainly by material shaping and/or material removal techniques. Material removal techniques such as turning, milling, drilling and grinding can be carried out on general-purpose machines, but involve wastage of material. Material shaping techniques such as casting, molding and forming require part-specific tooling, which are expensive and take a long time to develop. In general, current manufacturing processes consume a high amount of various resources: material, energy and labor. They are economical only when the end-requirement is large.

The first major development to reduce material wastage is the gradual move towards net-shape manufacturing processes, such as pressure diecasting, plastic injection molding, net-shape forging and powder metallurgy. The parts do not require any further processing and can be directly used or assembled with other parts to create the final product.

The second major development is freeform fabrication (initially called rapid prototyping) without part-specific tooling, suitable for one-off complex shapes. The part is fabricated directly from its digital definition, layer-by-layer. The layers are created by one of several techniques, such as photo-curing, matrix-deposition, powder-binding, and cut-stack-gluing. Current systems can produce layers approaching 0.01mm thick, but giving a 'staircase' effect and thereby poor surface finish. Current research is focussed on increasing the speed and surface finish of the parts, expanding the range of part materials (including metals) for such fabrication and incorporating multiple materials in the same part. A custom-made pen, with a paper-based body and plastic-based cap, coming out of such a system is not too difficult to visualize in the near future. Moreover, such systems can work unattended 24 hours a day, 365 days an year, significantly reducing the manufacturing cost of such custom-made parts.

The most recent and revolutionary development is nano or molecular manufacturing. The scanning tunneling microscope developed at IBM, USA in 1981 and its application for moving and positioning atoms in a pre-determined pattern has opened many new doors. This implies that a complex product, including its constituent parts of different materials, can be directly manufactured by moving appropriate molecules in appropriate positions, fast enough. While there is still a long wait for the day when a custom-made car, complete with body, chassis and engine will automatically emerge from a bath of material soup, physicists, material scientists and engineering researchers are excited about the prospect and working towards the goal.

3.3 Methodologies (enablers)

To ride the waves of new technologies, we need appropriate vehicles. We present four enablers: (1) Bionics and Reverse engineering, (2) Continuous Innovation, (3) Knowledge Management and (4) Product Life-cycle engineering.

3.3.1 Bionics and reverse engineering

The greatest of products and manufacturing processes created by human beings pale in front of the most complex machine of all, the human body itself. The well-designed bone structure with lubricated joints, blood cleansing and pumping systems, digestive and elimination systems, chemical production systems, information processing and communication systems in a human body put any man-made system to shame. Consider the visual organ alone, which packs a range of functions: sensing words/symbols, focusing, adaptation from light to dark, motion perception, distinguishing shadow, textures and 3-dimensions, adaptation from near to far, adaptation to flicker, color perception, etc.

Bionics is the study of nature’s materials, devices, processes and systems. The premise is that nature has already solved most of the problems we are grappling with. Biological systems are multifunctional, adaptive, nonlinear and complex; they have evolved over several millions years producing an equal number of ingenious methods and mechanisms.

Reverse engineering involves a detailed study of an existing product, usually made by a competitor, through disassembling its components if necessary, to determine its design (shape and dimensions), materials and manufacturing process, with the final aim of duplicating the product. An in-depth understanding of the relation between the product function, geometry, materials and process is essential to future improvements.

We manufacture new products made of alloys, plastics and ceramics using high temperatures, pressures and strong chemical treatments. Nature abhors this strategy. It manufactures its products under life-friendly conditions, at room temperature without harsh chemicals or high pressures, and with very little energy requirement. Bionics and reverse engineering together provide a powerful approach to solve our problems. They imply respect for nature, study of nature's products and processes, and their imitation to fulfill human requirements.

Nature’s engineering

Consider three examples that show how we can learn from nature: mussel superglue, spider silk and formation of shells. The marine mussel clings to rocks with a waterproof adhesive. Recently, scientists at the University of York, UK have succeeded in producing recombinant mussel adhesive protein in conventional microbial production systems, which could open the way to large-scale biotechnological production of one of nature's most versatile and powerful glues. The silk spun by the spider is one of the strongest materials on earth. Each fiber can stretch by 40% of its length and take several times as much load as steel (of same dimensions) without breaking. Unlike steel or polymer production, the spider uses extrusion and spinning at ambient temperatures, low pressures and water as solvent. Shells, pearls, bones and teeth are formed by layer-by-layer build-up. Unlike rapid prototyping technology, two or more materials are used, and the layers need not be flat nor concentric.

While biological systems excel in nano scale manufacture (using self-assembly, biomineralization and templating principles) there is also much to learn from nature in terms of macro manufacture and structure building. The Japanese have come up with a "pull" saw (instead of the conventional push saw), which cuts fibers in tension rather than shear. The inspiration is the wood wasp. Termites, honeybees, beavers, weaverbird and spider are some of the master structural engineers. The principles are being mimicked by researchers to build polymer foam structures and injection molding applications. The spider web structure has motivated the design of large solar sails.

Bionics is being recognized as crucial to materials science and manufacturing technology development and as a meeting point of academic, industrial and government scientists in disciplines as diverse as physics, chemistry, biology and mechanical engineering.

3.3.2 Continuous innovation

To achieve efficiency, reliability and recyclability approaching that of the nature, the current engineering products and processes need to be continuously improved through innovative ideas. This requires a passion for perfection, appropriate tools and techniques, and a creative environment.

The passion for perfection can only be drilled into engineers by setting the standards for quality and following them meticulously through discipline. The earlier definition of quality implied fewer manufacturing defects. Modern definition implies conformance to requirements, leading to customer satisfaction and delight, which is in line with Mahatma Gandhi's observation: "The customer is the most important person on our premises. He is not dependent on us, we are dependent on him. He is not an interruption of our work, he is the purpose of it. He is not an outsider on our business, he is part of it. We are not doing him a favour by serving him. He is doing us a favor by giving us the opportunity to do so." Future definitions of quality will imply pursuit of perfection in all activities related to manufacturing, and in terms of meeting the end requirements of not only the individual customer, but also all those affected by the product and its manufacturing process. This is characterized by "minimization of the total loss function" as proposed by Nam P Suh of MIT, USA.

The quality standards need to be continuously reviewed and improved in the pursuit of excellence. Well known standards include ISO 9000 and ISO 14000, promoted by the International Organization for Standardization (ISO). The ISO is a worldwide federation of national standards bodies from more than 140 countries, to facilitate global exchange of products and services. The ISO 9000 is mainly concerned with quality management procedures in an organization, including those for meeting customer satisfaction and applicable regulatory requirements, and for continually improving its performance in this regard. The ISO 14000 is concerned with environmental management, including procedures to minimize harmful effects on the environment caused by its activities, and to improve its performance in this regard.

Several tools and techniques for creative thinking and problem solving are available today. These essentially help in breaking the mental blocks or circumventing them to facilitate divergent thinking, followed by a systematic analysis of all alternatives to converge to the most optimal solution. Brainstorming (most effective in a group of 6-8, who agree not to criticize each other during the session) is a well-known technique. The "Theory of Inventive Problem Solving" (TRIZ) developed by a Russian Genrich Altshuller, based on a study of over 2 million patents, is being widely used for new inventions. He found that (1) problems, solutions and patterns of technical evolution are repeated across industries and sciences, and (2) innovations use scientific effects outside the field where they were developed. This again highlights the importance of cross-fertilization of ideas from different streams for continuous innovation.

Continuous innovation is also necessary for improving productivity and reducing costs. The productivity of labor in Indian manufacturing firms is less than 70% of China. While some Indian manufacturers are world leaders in cost competitiveness (such as TISCO and Hindustan Lever), there is a great scope for improvement in most of the industries.

3.3.3 Knowledge management

Knowledge is a distilled and abstracted form of information; information itself being an abstraction of data. For example, the numbers in a table are data, the table or graph of the numbers is information, and the equation capturing the graph is knowledge.

At present, the most important source of knowledge for manufacturing firms is from past experience, often gained by making costly mistakes. Other sources for new knowledge, as mentioned earlier, include bionics and innovation. Knowledge from any source is valuable, and demands a systematic approach for its storing, updating, exchanging and reuse. Conventional approach relied on physical means for documentation, duplication and transfer. The information technology has opened up completely new approaches for knowledge management.

We define three types of knowledge workers who will play an important role in realizing a responsible and sustainable model of manufacturing: seekers, keepers and users. The knowledge seekers will discover past (hidden) knowledge and create new knowledge by pursuit of science and technology. The knowledge keepers will be responsible for validating the above knowledge, preserving it through documentation and protecting it by various mechanisms for intellectual property rights. Finally, the knowledge users will apply it for practical purposes through various activities related to manufacturing, including maintaining a balance in nature by replenishing the materials and energy. These three are represented by the trinity of Hindu mythology: Brahma (for creation, aided by Saraswati for creativity), Vishnu (for maintenance, aided by Lakshmi for wealth) and Shiva (for recycling, aided by Parvati for energy).

Central libraries are the most visible form of knowledge repositories. Ancient libraries such as those in Alexandria and Nalanda were said to be storehouses of all human knowledge until that time. Scholars from different parts of the world would travel long distances just to study the books in those libraries. But the centralized storehouses have three problems: the loss of one or more rare books implies loss of that knowledge, the rapidly expanding human knowledge in various specializations can no longer be effectively stored in a single location, and the overheads associated with traveling to the library as well as searching and copying is a major bottleneck.

The modern decentralized approach to knowledge management involves storing the documents in digital form in different locations and linking them over an electronic network for search and retrieval. This is best exemplified by the web sites on the Internet. Documents in specific areas are usually maintained and continuously updated by experts working in that area. This approach applies to proprietary knowledge in a particular firm, as well as the scientific knowledge of the entire world.

It is now possible to search millions of documents (containing one or more desired keywords), stored in computers connected to the world-wide-web using popular search engines such as Google. The search and retrieval takes seconds, an unimaginable feat even a decade back. Such searches are increasingly being performed by software 'agents'. Future developments such as the proposed Semantic Internet coupled with intelligent agents will make it possible to search for even higher-level information, that is knowledge of solutions to specific problems.

Such search and retrieval programs can be coupled with data analysis programs, leading to 'data mining' systems. This essentially means discovering patterns in a given database, leading to new information. Taking a step further, future systems may perform 'information mining' leading to automatic creation of new knowledge.

3.3.4 Product life-cycle engineering

Let us now turn our attention to how specialized knowledge will be used for developing products in the near future. We will also see why product design, in its complete sense, is the most important activity.

It is well known that the product design activity accounts for less than 10% of its cost. It is also understood that the purchase cost of a typical product may be less than 10% of its total cost to society (energy consumption, maintenance, repair, impact on health and ecology). A good design of any product can significantly reduce its total cost, and it is well worth spending more resources on product design activities.

Product life-cycle engineering implies considering all aspects of the life of a product, to evolve an optimal design that satisfies customer requirements with minimal total cost to society. The complete design includes the detailed description (what, when, where, who, how and why) of geometry, materials, quality specifications and manufacturing process of each component in the product and their assembly. It also includes consideration of packaging, handling, maintenance, upgrading and disassembly (for reuse or recycling) of the product.

In theory, it is easy to modify the product design, especially at the concept stage, since it only involves erasing and redrawing the lines. In practice, it is quite difficult to determine which changes will reduce the total cost, because of the complex inter-relation between various parameters involved.

This has given rise to specializations such as design for ergonomics, design for energy efficiency, design for miniaturization, design for manufacturability, design for assembly, design for service and design for recyclability. Each of these considers the influence of a given product design on a specific aspect of its life. It includes application of experience-based guidelines for predicting potential problems and mathematical models for assessing and improving the performance of the product with respect to that aspect. All aspects are collectively referred to as Design for X (where X=assembly, service, etc.).

Each of the above specializations takes several years of practical experience to master, and can best be handled by experts. The limited number and availability of such experts leads us to an entirely new approach to product life-cycle engineering, referred to as synchronous collaborative engineering. This is an extension of what was earlier called concurrent engineering, and even earlier as integrated product-process task force.

Synchronous collaborative engineering involves several DFX experts located in different parts of the world, collaborating with each other in real-time to analyze and optimize the design of a product considering various life-cycle issues. This requires web-enabled technologies for product information management, on-line viewing/markup and video conferencing.

In future, special knowledge-based software programs called intelligent design assistants will provide real-time decision support to DFX experts. The assistants will be linked to domain-specific databases and knowledge management systems, and will continuously improve their own performance based on past experience.

4 MANUFACTURING POLICY FRAMEWORK

We have seen why manufacturing activities are important for creating and sustaining wealth of all types. We have also studied the past history of manufacturing, analyzed the present situation and glimpsed future technologies and methodologies. Based on these, we propose a new vision and mission for the manufacturing industry, as well as policies to catalyze the industry in India. The policies are presented as the interfaces between the Government, academia and industry with respect to manufacturing. To the extent possible, we have attempted to evolve fresh ideas in each policy and in line with the proposed vision and mission.

4.1 Vision and mission

4.1.1 Vision: balanced wealth creation

The vision should show the correct direction to align our manufacturing activities and help in assessing the current direction. The correct direction would be the one, which enables preserving and regenerating all types of wealth in a balanced manner. It must ensure prosperity for all levels of the society and for the current as well as future generations.

The proposed vision is: “To increase the prosperity for everyone in current as well as future generations, through creation and regeneration of all types of wealth – material, natural, intellectual and cultural – by encouraging and supporting appropriate manufacturing activities that respect nature and maintain a balance among various resources.”

4.1.2 Mission: leaders for manufacturing

There can be many ways of achieving the above vision: some faster than others, some which consume more resources than others, and some with more ‘side-effects’ than others. It would be impossible to exactly predict the technological developments and their effect on the society 10, 20, 50 or 100 years from now.

What we do know that it is the leaders who can make or break an organization or a nation, by inspiring their people and leading them to a magnetic vision by setting an example themselves. Good leaders are resourceful people who will rise against all odds, and build confidence and trust among the team-members. They will take the best decisions in the greater interest of the society, implement them passionately, and nurture new leaders to take their place.

Hence the proposed mission is: “To identify, train, deploy and support the leaders for manufacturing, who will excel in product and process innovation, be committed to their profession and society, and passionately work towards the vision of balanced wealth creation.”

The leaders of manufacturing will develop new products and processes, establish successful organizations related to manufacturing, and create wealth for themselves as well as for others. Every generation produces a few memorable leaders such as Jamshetjee Tata, Dhirubhai Ambani and Narayan Murthy. There are many more in all sectors, at all levels, but less well known. We need to turn the spotlight on them, so that others can draw inspiration and rise beyond the ordinary.

4.1.3 Policies for manufacturing

The manufacturing technology policy must be aligned with the above vision and mission. It must allow people in different organizations related to the Government, academia and industry to identify themselves with the vision and integrate their own work with others to achieve the mission.

The policy can be divided into four sets: academic policies, R&D policies, industry policies and economic policies. The first three sets of policies relate to the two-way interface between three bodies: Government, academia and industry.

The first set will deal with creating respect for manufacturing activities and a suitable environment for creating leaders. This can be best achieved by the interface between the Government and academia.

The second set deals with the creation of manufacturing leaders who will excel in product and process innovation. This is best achieved by the interface between academia and industry.

The third set deals with the role of such leaders – who may be placed in Government organizations or in industry – to create world-class organizations for manufacturing-related activities.

The last set deals with an overall operating system for all organizations to function smoothly and work towards the vision with minimal hindrances. The Government, in consultation and cooperation with the academia and industry has an important role to play in achieving such an environment.

4.2 Respect for manufacturing

The Government and academia together will create an environment that will enable creation of scientific knowledge applicable to manufacturing, foster the engineering leaders of tomorrow and gradually build respect for technology-related activities. The three are closely linked to each other, feeding each other. A critical mass of such leaders is necessary for the movement to sustain itself. Let us consider these more closely.

4.2.1 Favorable environment

Every child is born creative, but gradually develops mental blocks by the influence exerted by parents at home, teachers in school, friends in society and colleagues at work. Phrases such as ‘that is foolish’ and ‘it won’t work’ kill the creative enthusiasm of average people. Those who still defy the skeptics and keep working on their ideas are eventually brought down by a lack of resources to convert their ideas to reality. All people, whether recognized as creative or not, will benefit by an environment which respects and nurtures creativity.

A creative environment is one where the seeds of new ideas are produced by cross-fertilization from a rich variety of sources, grow into the trees of manufacturing facilities, and bear the fruit of products satisfying the needs of society. It is characterized by a freedom to think divergently, minimal noise and disturbance of all types, formal and informal mechanisms for networking for constructive criticism and cross-fertilization of ideas, and motivation, including social recognition.

At present, students enter an engineering stream after fiercely competing in an entrance examination covering Mathematics, Physics and Chemistry. The first year, when the students are keenest to learn about engineering, is usually spent reinforcing the same subjects. Secondly, there is a dearth of good teachers in engineering colleges who can fire the imagination of the students. They are primarily trained to be researchers, but have little or no industrial experience, no exposure to cutting edge technologies, no appreciation of local needs and no formal training in teaching and communication skills (unlike school teachers). Finally, very few engineering colleges have good laboratories; those that have do have, do not usually allow the students to tinker with the equipment.

As a result of the above, most students lose interest in engineering and move towards 'softer' options. It is estimated that at present, only 20-25% of engineering graduates from top engineering colleges take up manufacturing-related jobs (including CAD/CAM/ERP software); others opt for software jobs for service sector (30-40%), management studies or administrative jobs (10-15%) and higher studies abroad (25-30%).

Suitable policies need to be developed to overcome the three problems mentioned earlier and make engineering, especially manufacturing, more exciting to the students.

The first problem can be overcome by including holistic courses on science, engineering, economy, philosophy, communication and practical skills in the first year. The course on science could connect what the students have already learnt, but with an engineering viewpoint, focusing on scientific methods of inquiry, observation and experimentation, and their role in engineering. Similarly, the course on engineering could overview all branches, including their history, roles and inter-dependence. A study of economy, especially in the global context, is all too important. The course in philosophy will provide a link between the pursuit of science and technology, and the purpose of human existence and values. Courses in later years must also be designed to kindle and nurture the interest of students in engineering and technology. This requires the threads of theory and practical application to be woven together, tutorials on open-ended problems that require divergent-convergent thinking and exposure to emerging and future technologies in all areas. The curriculum must be prepared with active collaboration with the local industry.

Teaching in engineering colleges must be recognized for its importance in creating future leaders. Potential teachers must be trained in communication skills and provided a wider perspective on science, technology and society through designated mentors (senior teachers). They must have prior as well as periodic exposure to industry, at least through summer jobs. They must be respected and taken good care of.

The lack of good laboratories with the latest equipment, which are expensive to procure and difficult to maintain, can be addressed to some extent with appropriate multimedia education material and virtual engineering systems. These need to be prepared by a team of subject experts, communicators and multimedia experts.

In summary, the overall environment comprising of curriculum, teachers and lab facilities must lead the students through exposure and experience towards expertise and excellence in engineering.

4.2.2 Knowledge creation

Science and technology knowledge is perhaps the greatest asset of a nation, more important than physical assets such as machines and assembly plants. Multinational companies are happy to establish branch plants and fully owned subsidiaries in other countries, but fiercely protect their knowledge about the product design and its connection with the manufacturing process; technology transfers and licensing are no longer easily available. Every nation therefore, has to work hard to create, claim and commercialize its own niche areas of knowledge.

We have two sources for scientific and technical knowledge: discovery from ancient sources such as scriptures, and creation of new knowledge from science and technology. In addition, both streams must cooperate to cross-fertilize and crosscheck the knowledge for practical application, especially for manufacturing-related activities.

Modern science is based on inquiry, observation, experimentation, postulation and correlation to understand and explain the behavior of nature, and thus create new knowledge. Engineering involves the practical application of science to solve real-world problems, with the aim of utilizing materials and energy for human benefit. Technology is the application of engineering principles for a specific product or process. A nation must pursue all three: science, engineering and technology, for creating and applying new knowledge.

The Government research labs (see Table 4.1) in India include the 40 labs of Council of Scientific and Industrial Research employing over 22,000 persons, and the 50 labs of Defense Research and Development Organization, with over 30,000 persons. Academic institutes include over 500 engineering colleges (with over 100,000 seats), 750 medical colleges and 1000 polytechnics, besides 8000 colleges for arts, science, commerce and teacher training. There are about 40 autonomous technical institutes, including 7 IITs, 6 IIMs, IISc and 15 RECs (now NITs) supported by the Government. Today, India has the largest pool of qualified engineers, followed by USA, Germany and China.

Table 4.1: CSIR and Defense Labs in India

CSIR Lab	*Defense Lab*
Building Research, Roorkee	Aerial Delivery, Agra
Biochemical Technology, New Delhi	Vehicle R&D, Ahmednagar
Cellular & Molecular Biology, Hyderabad	Agricultural Research, Almora
Drug Research, Lukhnow	Combat Vehicles, Chennai
Electrochemical Research, Karaikudi	Proof and Experimental, Balasore
Electronics Engineering, Pilani	Aeronautical Development, Bangalore
Fuel Research, Dhanbad	Gas Turbine Research, Bangalore
Food Technological Research, Mysore	Electronics & Radar, Bangalore
Glass & Ceramic Research, Calcutta	Bioengg & Electromedical, Bangalore
Medicinal & Aromatic Plants, Lucknow	Aeronautical System Studies, Bangalore
Central Leather Research, Chennai	Microwave Tube R&D, Bangalore
Mechanical Engg Research, Durgapur	AI & Robotics, Bangalore
Mining Research, Dhanbad	Chemical & Metallurical Lab, Mumbai
Road Research Institute, New Delhi	Armament R&D, Pune
Scientific Instruments, Chandigarh	Terminal Ballistics, Chandigarh
Salt & Marine Chemicals, Bhavnagar	Naval Physical & Oceanographic, Cochin
Himalayan Bioresource, Palampur	Defence Science Centre, Delhi
Chemical Biology, Calcutta	Solidstate Physics, Delhi
Chemical Technology, Hyderabad	Nuclear Medicine & Allied Science, Delhi
Petroleum, Dehradun	Physiology and Allied Sciences, Delhi
Microbial Technology, Chandigarh	Systems Studies & Analysis, Delhi
Scientific Documentation Centre, Delhi	Fire Research, Delhi
Toxicology Research, Lucknow	Scientific Info & Documentation, Delhi
Aerospace Laboratories, Bangalore	Scientific Analysis Group, Delhi
Botanical Research Institute, Lucknow	Psychological Research, Delhi
Chemical Laboratory, Pune	Instruments R&D, Dehradun
Environmental Engineering, Nagpur	Electronics Application, Dehradun
Geophysical Research, Hyderabad	Food Research, Mysore
Oceanography, Goa	Explosive R&D, Pune
Science Communication, Delhi	Metallurgical Research Lab, Hyderabad
Metallurgical Laboratory, Jamshedpur	Electronics Research Lab, Hyderabad
Physical Laboratory, New Delhi	Materials and Stores R&D Estt., Kanpur
Structural Engineering Research, Ghaziabad	Defence R&D, Gwalior, Jodhpur, Hyderabad, Pune, Tezpur, Kolkata
Structural Engineering Research, Chennai	Armament Technology, Pune
Regional Research Lab, Bhopal	Naval Science, Visakhapatnam
Regional Research Lab, Jorhat	Snow Avalanche Study, Manali
Regional Research Lab, Jammu	Interim Test Range, Balasore
Regional Research Lab, Trivandrum	Advance Systems Integration, Bangalore
Regional Research Lab, Bhubaneshwar	Work Study, Mussoorie

Source: www.csir.res.in, www.drdo.org

Two types of bridges need to be built to significantly enhance the science and technology output of the nation. The first bridge is between the faculty of humanities, who may pursue the study of ancient science, and the faculty of sciences, who pursue the creation of new knowledge. While the two departments do coexist in most engineering colleges, there is little or no interaction between them. They need to work together to understand the ancient knowledge in the present context, validate it using modern scientific methods and find suitable practical applications. The second bridge is between the academic institutes and Government research laboratories. While the former have a young pool of bright students who can produce valuable seeds of new ideas, they do not usually have the sophisticated lab facilities to pursue the ideas further. The reverse is usually true in the case of Government research labs. Thus a close interaction between the two will be extremely fruitful and beneficial to the society.

The language for communicating and preserving the knowledge is also an important consideration. Our ancient scriptures are in Sanskrit, which is based on the Devanagari script familiar to a large proportion of the educated population. The Sanskrit language, whatever be its antiquity, is of wonderful structure, more perfect than the Greek, more copious than the Latin and more exquisitely refined than either – to quote Sir William Jones (British Orientalist, 1746-1794). The scientific and engineering community will immensely benefit by knowledge of Sanskrit. This will also help in protecting, to some extent, the native intellectual property rights and their commercial misuse by others. Indeed, Germany and Japan fiercely protect their science and technology knowledge by using their native language for technical literature.

4.2.3 Role of the media

The print and visual media has a very important role to play in creating a respect for manufacturing-related activities. Today, there is much discussion and consternation about the type of content published in newspapers, magazines, television, world-wide-web and movies, which greatly influence the minds and hearts of people, particularly the younger generation. The typical content includes news (political, business, social, sports and entertainment), advertisements, interviews, competitions, game shows, music, fiction and real-life based stories, most of which appear to contribute little towards promoting creativity, pursuit of knowledge and ethics, crucial for sustainable development. Even ‘infotainment’ appears to be primarily entertainment disguised as information.

While a few media houses and streams do publish more responsible content focussing on education, knowledge, culture and philosophy, the presentation requires a lot to be desired and certainly cannot compete with the lavish, glitzy and seductive nature of the other above mentioned content, which occupy prime spots and slots. Indeed, many parents are beginning to get concerned and trying to limit the exposure of their children to such content.

The Government and academia together, in collaboration with the media, can do much to reverse the current trend. The current resources and formats can be used for better content. For example, more news about science and technology can be covered, which has a longer appeal and impact. Some of the interviews with movie or sports stars can be replaced with inspiring leaders from the manufacturing sector, including innovators, researchers and mentors, who deserve a higher celebrity status. The ‘get-rich-quick’ type game shows can give way to science and technology shows.

Another way to draw the attention of all levels of the society to science and technology would be to organize mega events, say Science Kumbh Melas. We also need more popular science and technology writers and speakers, such as Jayant Narlikar. These require active contribution from academic and Government research institutes, and removal of hindrances on teachers and researchers to work with the media houses for promoting science and technology. Indeed, media houses can employ scientists and engineers to improve the scientific side of their reporting. Such policy decisions need to be framed and implemented by collaboration and agreement among all players.

4.3 Leaders for manufacturing

There is a widespread view that our graduates are good analysts but poor engineers. It not surprising, since this profession is largely taught by non-practitioners, focusing only on theoretical aspects. Further, a mediocre environment and indifference to engineers in the industry – the jobs are perceived to be neither exciting nor paying – is forcing them to prepare migrating to other professions or countries, well before the completion of their studies.

There is an urgent need to bridge the gap between theory and reality, and bring engineers back to the manufacturing industry. The academia and industry together will take up the responsibility of creating and deploying leaders for manufacturing and their innovative ideas. We present three policies to achieve this: (1) innovation centers in academic institutions, where potential leaders can be identified, (2) mutual exchange chairs in academia and industry, which will bring the two closer and create new opportunities for training and nurturing innovators, and (3) compulsory internship for engineers in manufacturing industry to ensure a smooth transition between theory and practice.

4.3.1 Innovation centers

An innovation center should be a place where new ideas for products and processes are seeded, developed, tested and preserved to further seed new ideas. It will be the breeding ground for future innovators and leaders of manufacturing industry.

The vital first step is to draw academics, researchers and industrialists into informal meetings, necessary for seeding new ideas. This can be ensured by organizing frequent, even daily, seminar talks at the innovation center and making it an attractive place to draw people – open spaces, curved paths, flowering trees, artificial waterfalls and a café will help.

The seminar talks can be about challenging problems (that need new solutions) and emerging technologies (that need new applications) by faculty, research students and industrialists. Such talks will overcome the limitations of traditional seminars in departments, which attract little audience and narrow discussions. The calendar must be announced well in advance and easily visible or accessible. Yet the presentations must be short and open-ended. The aim is to ensure a large number of inter-disciplinary audience and extended discussions.

Further development of the ideas requires the following facilities in the innovation center: (a) access to a comprehensive database of materials, products, processes and patents along with facilities for search, comparison and retrieval, (b) quiet rooms and appropriate facilities for presentations and discussions among small groups, including video-conferencing with experts, (c) software and hardware for virtual and/or real prototyping to analyze and test the ideas, and (d) facilities for documentation and IPR generation.

The centers should maintain strong links with laboratories within the institution, as well as regional and national labs, for detailed testing and pilot production studies. Other links include legal experts (for IPR issues), financial institutions (for seeking investors), and potential entrepreneurs (for commercialization). An inspiring and resourceful person must head the center and help in establishing a successful track record of innovations in the first year itself.

The overall focus and strategy of an innovation center may be evolved in consultation with local industry. The R&D may be geared towards breakthrough ideas, import-substitution or export-oriented products.
The industry must recognize the importance of R&D and the contribution of such innovation centers, for ‘high-tech’ as well as ‘low-tech’ products. It is said that one rupee invested in a meaningful R&D project returns an average of five rupees over the next five years. Korea invests 2.5% of its GDP in R&D, of which industry share is 80%. In contrast, India spends 0.7% of its GDP on R&D, of which industry share is only 26%. Another indicator is the ratio of R&D expenditure to turnover, which is 0.6% in Indian industry against a world average of 2.5%. An exception is the aggressive R&D programs of Indian pharmaceutical firms (5-8% of turnover), which is giving them a global competitive advantage today.

Thus manufacturing firms must invest a significant portion of their turnover depending on the sector and strategy in R&D; a part of this should be invested in local innovation centers. While they must understand that R&D takes time, they must also insist on project, cost and quality management practices to be followed for R&D projects funded by them. The projects must be on partnership basis (not one-sided funding) with clearly defined goals, sharing of intellectual property rights and accountability. Students working on such projects must share the rights, encouraged to join the industry and work towards bringing new products to the market.

4.3.2 Mutual exchange chairs

This policy envisages the establishment of mutual exchange chairs between academia and industry. This means that a professor will spend his time in a manufacturing company while the industrialist (from the same company) spends an equal amount of time in the academic institute.

The chair (in either academia or industry) implies a separate room with meeting and communication facilities, and access to people, facilities and documentation. The exchange will on a barter basis (no charges for the time spent). It will be on an equivalent level, based on qualifications and work experience; for example: full professor for director or vice-president, associate professor for general manager, assistant professor for manager, etc. for similar sized organizations. The exchange need not be limited to the same discipline; a Chemistry or Aeronautical professor may well find something to learn from and contribute to an automobile or mobile phone manufacturer. There will be mutual trust with respect to confidential information and intellectual property. We feel that the minimum duration for such an exchange should be one working week to be effective.

After joining the academic institute, the industrialist will be expected to give a few lectures as a co-instructor in close coordination with the main instructor of the course. This will force him to get back to the books and basics, throwing new light on his practical experience. The industrialist will be able to engage in discussions with other faculty and students, and explore the technical literature, including the reports of research carried out at the institute. These might help in troubleshooting existing problems, gaining a better perspective of his current direction and finding new ideas for further exploration. The industrialist may even be able to identify future employees, and lay a path for them through practical training and sponsored projects.

During his tenure in the industry, the professor will be able to try his/her analytical skills to assess the products, processes and problems. He/she will have access to practical data useful for improving course material and teaching. He/she may also find that there is already a solution (own or from technical literature) that could be tested on a current problem in the company. He/she can discuss the ideas with the engineers, and carry out experiments for data collection. The professor may also be in a better position to formulate practical training programs for students. Finally, he/she will be able to guide the creation and documentation of industrial case studies, useful for preserving the company's knowledge and teaching novice engineers.

The academic institution will gain from the practical experience of the industrialist, while the industry will gain from the analytical approach of the professor. This will improve the teaching in academia and research in industry. Both sides will be able to appreciate each other's strengths and limitations. Problems and solutions will meet each other. The discussions will lead to the formulation of meaningful research projects that have practical application.

In the process of the above exchange, the students will benefit greatly. They will gain a better understanding of the connection between theory and practice through real-life examples in teaching, meaningful projects and better practical training programs. They will get more interested in engineering. Some of them will get excited enough to pursue a career in engineering, instead of other 'softer' options.

The industrialist in academic institute will be able to easily identify engineering students with a passion for practical innovation. Similarly, the professor will be able to quickly pick out practicing engineers with an analytical brain. Future leaders of manufacturing can thus be spotted and provided a fast track, if necessary.

4.3.3 Compulsory internship

Every other professional education, such as medicine, architecture, law and accounting, includes a compulsory period of internship for a year or more. It involves training under a practising professional in a real-life environment, to handle real-life situations under his/her supervision. The interns usually work long hours in difficult conditions with very little financial compensation. This however, helps build their confidence and self-esteem as well as develop a deeper interest and devotion to their respective professional careers. The internship, coupled with compulsory service in some professions (for example, service in Government hospitals or rural areas for medical students in some States) extends the total duration of the professional study, leading to better competence. It also filters out those who may not be sufficiently interested or committed to the profession.

Engineering, particularly manufacturing, is also a practical profession, but engineers do not have the benefit of such internships. Their contact with the industry (during their college years) is usually limited to two months of practical training and pre-placement talks, both of which provide only superficial exposure. The manufacturing companies are neither geared for nor interested in providing the 'finishing' education to manufacturing engineers, since they are not certain of them joining their organization or even the profession. As a result, engineering has become a 'fast' and 'light' professional degree, and engineering students rarely pursue their career in the same profession.

We propose a compulsory internship-cum-service of one year after the completion of four years of engineering studies. The service can be in any organization where manufacturing knowledge can be directly applied, including industry, research and academic institutions.

To ensure compliance, the award of the engineering degree or a widely recognized professional certificate can be linked to the completion of internship. Such a certificate can be made mandatory for admission to post-graduate studies in engineering and public sector units.

The internship may be linked to the final year project. To ensure better participation and results, the internships available in different organizations may be advertised in advance and competed for.

The policy will discourage those who may not really be interested in engineering from entering the stream in the first place. This will indirectly reduce the indiscriminate proliferation of engineering colleges without adequate facilities and teachers.

The industry must ensure that engineers who prove themselves in the internships find respectful placements on par with other professionals with an equal number of years of study and experience.

4.4 Synergic manufacturing

The policies related to the interface between industry and Government (including Government R&D laboratories) will nurture and support the leaders for manufacturing and facilitate successful commercialization of ideas to create world-class companies. The R&D scientists can get involved in creating a new manufacturing firm or facility. The firm can rapidly grow by focusing on its core competence, as well as its resources and markets, and catalyzing the creation of supplier firms. We call this the dendritic model. Large firms can become the backbone of a cluster, and grow in size and reach along with the family of suppliers in the cluster. The firms in the cluster cooperate with each other to create common facilities, including infrastructure, training, R&D and brand building to further expand and consolidate their position in the world market. These are described in detail here.

4.4.1 Focus sectors

India would have a natural advantage in those areas of manufacturing, which have the following characteristics: (1) availability of local raw materials, (2) application of local manpower capabilities, (3) low capital and inexpensive technology requirement, and (4) good demand at both domestic and global level. Two areas that fulfill all these characteristics are: (1) agri-centric skill-intensive products, and (2) metal-based engineering-intensive products, explored here.

India is blessed with diverse geographical and climatic zones conducive for producing a large variety of agricultural products. It ranks number one in terms of milk, tea, jute, pulses, groundnut, fruits and vegetables production; number two in terms of rice, wheat and sugarcane; and number three in terms of cotton production worldwide. Exports of these items contribute about US$ 5 billion annually, accounting for about 20% of total exports from India.

Only about 1.5% of the total production of fruits and vegetables is processed into secondary and tertiary products, while about 20% to 30% of the harvest goes waste for want of storage capacity, marketing outlets and inadequate number of processing units. Indeed, the portion of raw food items processed into value-added products up the food chain is one of the lowest in the world. Thus there is a tremendous opportunity for the manufacturing sector to build upon the advantage we have in terms of the types and the quantity of produce by adding value to the agricultural products.

For example, there is a vast market for the diary-based products such as butter, cheese and ethnic sweets, locally as well as for the large number of Indians scattered all over the world. Another example is packaged wheat flour and bakery products. Similar opportunities exist in the field of poultry and marine products by ensuring quality and adding higher value by creating secondary and tertiary products. There is a great demand for packaged drinks and convenience foods that require little preparation. There is a growing demand for ethnic Indian food products all over the world.

Manufacturing firms need to invest in research, design, development and maintenance of machinery (suited to rural Indian conditions) for agri-based products. An important direction of R&D is automation in food processing industry because of the need for preservation of food, quality awareness and time constraints due to urbanization. Another focus area is new tools and aids for process control and measurement of quality properties. Finally, large-scale production, processing and storage of ethnic Indian food is needed to tap its potential.

Take the case of fruits where the uniformity in texture, color and shape of fruit are important criteria that decide the price in the international market. Automatic machines (based on technologies such as computer vision, image processing and artificial intelligence) for sorting fruits based on the above criteria can help in tapping the large market that exists for tropical fruits.

Indian cultural and ancient medicine can also be tapped to create new food products for the global market. For example *jaggery (gur)*, which is an important ingredient of the Indian diet has proven health benefits over sugar. This requires development of efficient furnaces for boiling of sugar cane, inexpensive (non-chemical based) technology for reducing impurities and forming techniques for *jaggery* products in different shapes and convenient sizes.

The scientific community and service sectors need to complement the farmers and manufacturing industry through improved seeds for agricultural and horticultural produce; agricultural biotechnology; post harvest activities, bulk storage (including silos and temperature controlled warehousing); packaging, transportation and logistics; port handling equipment (loading and unloading); cold store and cold chain management of agricultural, horticulture and fish products.

Other services include access to best practices in precision farming, affordable credit, crop insurance, farm inputs and modern equipment in order to increase productivity. There is a need for creating a partnership web between the farmer and agri-input companies, banks, insurance companies, grain handling, storage companies and manufacturing firms. This will also help in better marketing and for creating brands in agri products industry.

The textile industry is also an agri-based industry in which India has a traditional advantage. Cotton-based textiles and ethnic designer wear are witnessing a steep growth in demand. Our competitive edge must be strengthened by increased R&D outlays in every aspect of the product-life cycle, starting from raw material production to fabric production to apparel manufacture.

The second focus sector is related to *metal-based engineering-intensive products*. This follows three strong factors: (1) the country ranks among the top ten in terms of major minerals, and already has world's lowest cost producers of iron and aluminum, the top two engineering materials; (2) we have the world's largest pool of engineers (about 100,000 seats per year); and (3) our world class capability and confidence gained in information technology can be readily applied to the domestic manufacturing industry, for product innovation, process control and supply chain management.

The starting point would be establishing dominance in sub-assemblies for top OEMs, and gradually move up the value chain toward full products and finally branded innovative products. Companies like Bharat Forge, Pune (world's largest and most technologically advanced forging shop under one roof), Sundaram Fasteners, Chennai (which won GM's Supplier of the Year Award for seven years in a row) and Shriram Pistons & Rings, Ghaziabad (India's largest exporter of pistons and piston rings) are setting examples for others to follow.

4.4.2 Proof to product

Out of a thousand ideas for new products, only 100 reach prototype stage; of these only 10 get manufactured and reach the market; and only one becomes a blockbuster product that significantly pushes the company's fortunes. With increasing complexity of technologies and products on one hand and the intense competition in the market place on the other, the costs and risks involved in bringing a new product to market have skyrocketed.

Because of the ready accessibility to scientific information and technological advancements, several companies worldwide would be working on the same idea at any given point of time. The one who reaches first to the market grabs the attention of potential customers and the major share of the total market, limited only by capacity. Such companies derive half or more of their revenues from products introduced in the previous 2-3 years, and maintain their leadership by aggressive R&D and product innovation.

A close relation between innovator-entrepreneurs, financial institutes and Government R&D laboratories will minimize the cost and risk associated with new product development and commercialization. All three parties will be closely associated with each other in all three phases: project review, pilot production and commercialization. When an entrepreneur approaches a financial institute (bank, fund manager or venture capitalist) for funding a new project, they will involve a scientist from a suitable R&D organization to review the project proposal and analyze the key concepts. The same scientist will also assist in prototype fabrication, detailed testing in laboratory and pilot plant production based on the facilities available with him and other national laboratories. The scientist can also be a part of the board of directors of the company, guiding the establishment of regular production, marketing and continuous improvement.

Such a relation will ensure: (1) technical back up and support to the innovator-entrepreneur to refine the idea and overcome technical obstacles, or even to ascertain when to abandon an infeasible or uneconomical idea; (2) higher confidence to the financial institute about its investment, leading to higher investments with lower calculated risks; and (3) better utilization of scientists and facilities in national labs for national purposes, as well as incentives in the form of financial returns and social recognition.

4.4.3 Cooperative Clusters

A cluster comprises several small and medium enterprises in a single location, competing or collaborating in a common industry, sharing common resources including infrastructure and labor pool, producing and selling a range of related and complementary products and services.

A cluster may be formed naturally or induced artificially. Natural clusters are formed by private initiative, usually in a place where raw materials and specific skills are already available (for example, marble cutting in Kisangarh, Rajasthan). Alternatively, the cluster may be induced by Government policy or by a large customer (for example, the automobile ancillary in Gurgaon induced by Maruti Udyog). In either case, the cluster gradually grows by the initial success of one or few entrepreneurs. Other units that come up either collaborate with the original units (as suppliers and service providers) or compete with them. The number of competing units grows, building up capacity. This forces the units to focus on cost reduction and productivity improvement. In an extreme case, weak units die out, leaving the remaining units more space to operate and grow healthily. This is exemplified by the electric fans cluster in Calcutta, which went through a phase of growth, weeding out and consolidation.

The clusters can be classified as horizontal and vertical. Horizontal clusters comprise of units that essentially compete with each other to manufacture the same product. Each unit performs all the steps from processing of raw materials to manufacturing and selling of finished products. It is thus usually applicable to simple products such as sports products in Ludhiana. On the other hand, vertical clusters are characterized by products that require a higher degree of specialization or facilities for different stages of manufacture. This forces the units in the cluster to depend on and collaborate with each other. An example of this is the hosiery units in Tiruppur.

There are about 350 small scale industry based clusters in India, in addition to approximately 2000 rural and artisan based clusters (see Table 4.2). Some of these clusters account for over 50% share of the market in a particular product. For example, Panipat produces 75% of the total blankets in the country; Coimbatore contributes to 80% of country's cotton hosiery exports; Agra has about 6800 units making 150,000 pairs of shoes per day, and exporting over US$50 million worth shoes per year. The small scale industry contributes 40% to the country's industrial output and exports products worth nearly US$20 billion. Over 14 million people are employed in such clusters, mainly in farm-based products (13%), followed by non-metallic mineral products (12%) and metal products (10%). The state of Maharashtra has the largest number of clusters, many of them induced by industrial development.

The Government of India recognized the importance of clusters in the years after Independence, and intervened by reserving 'whatever can be produced by small cottage industry' to this sector only: over 800 items by late 1980s. This however, forced the units to remain small (or split up) to take advantage of such reservations. This in turn limited the investments in equipment (necessary for economies of scale), product R&D (necessary for innovative features), process improvements (for quality and productivity improvements) and management systems (for better strategy, linkages and market share). Thus the wave of globalization and liberalization found many Indian clusters in a poor position to compete globally.

Table 4.2: Major clusters in India

Products	*Cluster*	*Prod. Rs.Cr/y*	*Exports Rs.Cr/y*
Cashew processing	Sindhudurg, Palasa	30	Nil
Fruit processing	Chittoor	20	-
Carpets	Bhadohi, Chunnar, Kashmir	-	-
Leather, leather products	Madras, Kanpur, Agra, Howrah, Tangra, Topsia, Tiljola		8500
Sports Goods	Meerut	350	90
Matches, fire works	Sivakasi, Kovilpatti	129	7
Towels, blankets, covers	Panipat	NA	406
Textiles	Panipat, Sanganer, Palli, Jodhpur, Jetpur, Surat, Mysore, Bhiwandi, Sambalpur, Bhilwara, Coimbatore, Salem	-	20,000
Readymade garments	Ahmedabad, Bangalore, Mumbai, Delhi, Tirupur, Ludhiana, Calcutta	-	18,000
Woolen Knitwear	Ludhiana	95%	-
Glass Industry	Firozabad	1000	300
Ceramics	Khurja, Thangadh	200	50
Castings	Rajkot, Jaipur, Batala, Agra, Hyderabad	525	20
Engg. Fabrication	Nagpur	17	NA
Cast iron pipes	Howrah	940	240
Rerolling	Bhavanagar	NA	Nil
Steel Rerolling	Howrah	1430	
Machine Tools	Ludhiana, Batala, Bangalore, Coimbatore	-	-
Brass Parts	Jamnagar	350	50
Bicycles & Parts	Ludhiana	60%	-
Automotive Parts	Okhala, Rohtak, Hyderabad	295	55
Diesel Engines & parts	Rajkot	500	100
Fans, Motors, Pumps	Varanasi, Hyderabad, Coimbatore	350	-
Transformers	Mau Aima	-	-
Dry Cell, Battery	Howrah, Midnapur, Siliguri	-	-
Electronics	Hyderabad	50	-
Sc.Instruments	Ambala	NA	26
Survey Instruments	Roorkee	100	35
Pharmaceuticals, Drugs	Delhi, Ahmadabad, Hyderabad	200	-
Basic drugs	Thane, Belapur	8220	1410
Gems and Jewelry	Tiruchirapalli, Jaipur, Surat	-	25,000
Lock Industry	Aligarh	135	55
Balance Scale	Savarkandla	1000	NA
Dyes	Ahmadabad	550	NA
Sanitary Fittings	Okhala	30	7
Handicrafts	Many towns	1100	20

National Institute of Small Industry Extension Training (NISIET)

A ‘dendrite’ model, borrowed from materials science, explains the formation and healthy growth of manufacturing clusters, as follows.

The firms in the cluster draw upon the local resources to create products and sell them in the market. The hierarchy of suppliers (first-tier, second-tier, etc.) may represent the entire population in a cluster area. The firms grow as long as they do not directly compete with each other, though they may share common suppliers and resource pool. Their rate of growth will initially be very high, but gradually reduce as the resources diminish, products get bigger or complex, and the market gets saturated.

The policies must be tuned to the phase of growth of a given cluster. During the initial phase they must ensure adequate supply of resources (labor, energy and raw materials) through a suitable infrastructure. During the growth phase, the cluster will require support for strengthening and expanding the market. Later, the firms in a cluster need to be supported in their efforts for product innovation and process improvement.

In general, the firms in a cluster need to be encouraged to cooperate in common areas (such as basic research) and compete in terms of process (productivity and costs) to develop their individual core competences.

A cooperative is an autonomous association of persons united voluntarily to meet their common economic and social needs through a jointly-owned and democratically-controlled enterprise. The members of a cooperative accept a fair share of the risks and benefits of their undertaking.

Amul

The farmer-owned Amul co-operative in Anand, Gujarat – initiated by Dr. Verghese Kurien, a Mechanical Engineer from Madras University – showed how an integrated and cooperative approach enhances production, procurement, processing and marketing of milk. A village cooperative society of primary producers is formed under the guidance of a supervisor of the district level cooperative owning the diary processing plant. A milk producer becomes a member by paying a nominal entrance fee and agrees to sell milk only to the society. Each society has a milk collection center to which the farmers take their milk in the morning and evening. The cooperative also standardizes methods of procurement, processing and quality control of milk, assuring the producer/farmers of fairness in these procedures. The collected milk is weighed, tested for fat, pasteurized and converted into various milk products as per the product mix provided by the state-level dairy federation that markets the products of all the dairies in the state. Surplus milk from the dairies, after meeting the local liquid milk requirement and conversion into various products, is sent to mother dairies situated in metro cities by road or rail milk tankers, some as far as Calcutta (2,200 km away). This is sold in urban centers in plastic pouches (packed at the district dairies) through vending booths. The Gujarat Cooperative family now comprises 12 district unions with over 10,000 societies involving 2.2 million members supplying over 4.5 million liters of milk PER DAY. Today Amul brand has become synonymous with a range of milk products including butter, cheese, milk powder, diary whitener, ghee, paneer, pizza, curd, cream, ice creams, sweets and chocolates: over 25,000 tonnes (sales US$500 million) per year. This success story, which provided a regularized and standardized link between the rural milk supply centers and the urban demand centers has now been replicated in other states.

India has the largest number of cooperatives: about 90,000, who spearheaded and benefited from the ‘green revolution’ and ‘white revolution’, contributing to India’s number one position in milk production, and number two position in rice as well as wheat. There are over 50,000 dairy cooperatives, with several million members. Indeed, India excels in *production by the masses, instead of mass production by a few*. Other notable examples include the healthcare cooperatives in Brazil with over 60,000 doctors taking care of 8.5 million patients and the credit cooperatives in Korea with $8 million in assets and 3 million members.

The cooperative model can be successfully applied to manufacturing clusters, especially when a large number of small firms, making the same or similar product, already exist in a cluster. These firms will form a cooperative to procure raw materials (at a lower cost), add value to their products (by finishing, assembly with other components and suitable packaging), create a common brand and market the products under that brand name. The cooperative can also invest in common R&D facilities and training institutes. All these require large investments that may not be possible by individual firms. In other words, the cooperative will form the backbone of the entire cluster, lending it strength coupled with flexibility.

4.5 Information technology

There are two compelling reasons why information technology (hereafter IT) will have a critical role in the resurgence of Indian manufacturing industry. The first is the proven benefits of IT in terms of ease of creation, archival, retrieval and transmission of information; elimination of intermediate tasks; and automation of routine tasks. Virtual storage and digital movement instead of physical storage and movement greatly reduces the cost and increases the speed of activities related to information and knowledge management. It also enables concurrent participation of team members and facilitates better and faster decision-making. All this leads to dramatically higher competitiveness of manufacturing firms.

The second reason is the proven world-class capability of Indian firms in developing, providing and using IT-based products and services. Indian IT firms have acquired global exposure, skills and confidence in providing high quality services and in contributing towards software products in many sectors including finance, communications, transport & travel, manufacturing and others. A significant proportion of this work force was drawn from engineering, and the tremendous growth of IT industry was at a cost to the domestic manufacturing sector. Now, with a downturn in global business scenario, many IT firms are exploring opportunities within the country. The manufacturing sector must come forward and take advantage of this situation by claiming its engineers back.

In the following sections, we will review the application of IT to three sets of activities: design, production and supply chain management.

4.5.1 Design activities

The design phase starts from the inputs of market research and ends with the detailed specifications of the product. The three major phases include (1) determining customer needs and functional requirements, (2) evolving the concept and system design, and (3) engineering design, analysis and prototyping. Depending on the phase, the composition of the design team includes more of market researchers, industrial designers or engineering design engineers.

A complex product such an automobile or aircraft comprises several assemblies, sub-assemblies and components, and requires several hundred engineers who may be working on different components or sub-systems in parallel. A high degree of collaboration and mechanisms for design conflict resolution are necessary to achieve compatibility between different sub-systems and overall optimization in terms of cost, quality and lead-time. The Boeing 777 was developed by 230 teams with 10 to 20 members each.

The three most important concerns are: (1) the designed product must meet the customer requirements, not only when the product is launched, but for several years after that, and maintain a lead over competing products; (2) the total cost of the product, including meeting all obligations, must provide a healthy profit margin at the expected price even in a highly competitive market; and (3) the product must reach the customers in the shortest possible time, well before the nearest competitor, to establish a lead and grab a larger share of the market. We call these factors as P-Q-R (Price, Quality and Response).

IT helps design engineers in three major ways. It enables large databases of customer inputs, materials, standard components and even concepts (patents) to be quickly searched to retrieve the desired information and reuse it in the current project. This not only saves time (by several orders of magnitude compared to manual searching) but also eliminates redundancy and 'reinventing the wheel'. Moreover, IT enables management of knowledge (know-how as well as know-why) related to previous products in a systematic manner, so that even novice engineers can develop new designs with a high level of quality and productivity.

The second major use of IT is the availability of accurate and up-to-date information about the product and project to all team-members. The consistency of design across sub-systems can be automatically checked, enabling continuous (instead of periodic) review of the project and early resolution of any conflicts through discussions. Such discussions could be carried out even if team members are located far apart, by use of on-line systems for design viewing, markup and video conferencing. Any change can be automatically recorded in the central database and transmitted to all concerned members.

The third major application is in computer-aided design (CAD), analysis (CAE), process planning (CAPP) and manufacture (CAM), collectively referred to as CAX. The backbone is a 3-dimensional model of the product, created by a solid modeling software. All these software tools enable simulating the performance of the product and process to predict potential problems and preventing their occurrence through suitable changes at the design phase itself. The solid model can also be used for designing the tooling and fabricating prototypes. The virtual and real prototypes greatly reduce the probability of unexpected problems during actual production.

4.5.2 Production activities

The production activities start from manufacturing resource planning and end with shipping of the product. Manufacturing Resource Planning takes off from the process plan generated by the design team, and includes materials planning, production schedules and shop floor control functions. The actual production may involve manual, semi-automatic and automatic functions. The last stages include assembly of different components into sub-assemblies, further into assemblies and finally the complete product. Some of the components and sub-assemblies may be obtained from suppliers. The product is finally tested, packaged and shipped to the customer or an intermediary.

The three most important issues in production phase include: (1) achieving the specified quality consistently and during the process itself, through process automation, in-process control and real-time inspection, leading to zero defects; (2) continuous improvement in productivity, measured in terms of material flow time through the system and work-in-progress; and (3) continuous reduction in costs by minimizing wastage of all types of resources, including material, inventory, energy, labor and transportation.

The use of IT greatly helps in achieving the above. Software programs help automating process planning and manufacturing resource planning functions to a great extent, usually by drawing upon previous plans stored in a database. It is possible to coordinate the detailed plans of different units within the factory to achieve a smooth flow of products while maintaining a high level of resource utilization.

Computer-aided process control for continuous processes, numerical control for machine tools and robots (for welding, painting, transportation and assembly operations) help in achieving consistent quality, high productivity and safety. They have also reduced costs in countries or sectors where labor costs are high.

Modern IT systems also enable anticipating machine breakdowns by continuously monitoring process signals and analyzing abnormalities in real-time. The systems can even initiate corrective action to prevent production bottlenecks.

The high initial cost of automation is offset by making the systems flexible (referred to as flexible manufacturing systems) to quickly handle changes in product definition or order requirements. Once all activities from design through process planning to production are handled or assisted by computers, they can be integrated for seamless flow of information. This is referred to as computer-integrated manufacturing.

4.5.3 Supply chain management

Owing to the increasing complexity of products in terms of number of parts and/or the high degree of specialization required for designing and producing individual parts, it is not possible for a single manufacturer to produce all of them in-house. It is not uncommon for a modern automobile or aircraft to have over 90% of parts in terms of number and 75% by value being outsourced. There may be several levels of suppliers; suppliers of sub-assemblies may themselves outsource the components from suppliers at an even lower level.

The tasks involved in managing the supply chain include (1) selecting the best supplier for a given sub-assembly, based on a number of criteria such as production capacity, flexibility, quality systems, cost competitiveness, delivery capability and continuous improvement; (2) collaborating with the supplier to fine-tune the design of the sub-system and mating systems to improve reliability, reduce cost and compress development time; and (3) coordinating with the supplier to receive quality-certified sub-assemblies just-in-time at the assembly plant, so as to avoid inspection and inventory build up, but without creating production bottlenecks.

Software tools for supply chain management provide functions for planning (forecasts and schedules) as well as execution (dynamic management of activities). These include: enterprise resource planning, supply chain planning, order management, warehouse management and transportation management. These have received a great amount of attention in the industry, as indicated by the total sales steadily increasing from under $1 billion in 1995 to over $10 billion in 2002. Major vendors include Oracle, Baan and SAP.

Mahindra & Mahindra

The development of the Scorpio, a sports utility vehicle by Mahindra & Mahindra, is a good example of integrated product design, production planning and supply chain management aided by information technology. Mahindra & Mahindra is an automobile major with 17000 employees in two divisions producing commercial vehicles and agricultural tractors respectively, with an annual sales of rupees 4000 crore (US$800 million). Scorpio was envisaged in 1996 as a vehicle that would be world class in terms of the product, process, positioning and launching. It was developed completely from scratch by a team of 120 engineers with an average age of 27 years. They built 74 prototypes and ran them through 1 million km to validate the design. Over 95% of the parts were sourced from suppliers, who collaborated closely with the design team right from the beginning. The suppliers were made responsible for defining, designing, developing and eventually delivering the sub-systems with self-certification. These are assembled in a state-of-the-art plant with a moving line based on single flow concept, with an annual capacity of over 40,000 units. The plant has a fully automated press shop, die shop, body shop and paint shop. The total investment in the Scorpio project is about US$120 million, with major shares going to the plant (60%), vendor development (20%) and product development (15%). The Scorpio team recognizes that excellence is not just a product or a process, but an attitude that says, “Nothing else will do”.

Thus, information technology facilitates cooperation and coordination across organizational boundaries in a supply chain. Recognizing the importance of data as a corporate resource, organizations are building data warehouses so that different functional areas can easily share consistent information. The advent of enterprise integration systems enables close coupling of business processes and tight coordination of work and information flows. This in turn allows firms to increase customer focus and manage the relationship; plan and monitor all organizational processes; and continuously reengineer and improve business processes.

In future, cheap microprocessor chips and electronic 'tags' will enable gathering vast amounts of detailed data on material and information flows, and on the states of resources and processes. For example, a truck delivering products can be continuously monitored using global positioning systems, and can be dynamically rerouted if necessary. Individual items within the truck (with electronic tags) can also be continuously monitored, not just at loading and unloading points and at machine posts.

In summary, information technology facilitates management and flow of information across different activities, supply chain and sectors. Many manufacturing firms have successfully adopted IT for all activities – design, production and supply chain management – to establish a clear competitive edge over others.

There are three major bottlenecks hindering the penetration of IT products and services in manufacturing sector, especially the small and medium firms. These are: (1) lack of awareness at all levels in an organization, that is top, middle and operation level, about different IT solutions, their applications, benefits and limitations, and returns on investment; (2) lack of qualified and trained engineers to use and maintain the IT solutions, including the problem of retaining such engineers in the company; and (3) the high cost of acquiring and maintaining the IT systems.

The above problems need to be tackled by adequate policies. Practicing engineers must be mandated to undergo a minimum period (at least 15 days) of training every year to learn about new technologies, including IT solutions. This policy is common in many Western countries. The high cost of IT solutions can be brought down by indigenous development. Bodies such as National Informatics Center are well placed to coordinate such development efforts. Until such time, the cost may be reduced by bulk licenses, soft loans from banks and tax incentives such as those given for R&D investments.

4.2 Operating system

Just as an operating system in a digital computer provides a backbone and a user-friendly environment for smooth functioning of various programs, the importance of a suitable operating system for the manufacturing industry can hardly be over-emphasized. The provision of local infrastructure, promotionary economic policies and transparency and accountability assume prime importance. These will enable tapping the full potential of Indian industry. In order to promote production and geographic distribution of infrastructure, it is essential to involve local population in developmental plans. Right now, the devolution of resources takes place from top to bottom and the local initiatives and participation in envisaging the developmental plans have not become the order of the day.

We have already seen in the section of competitiveness that the inadequacy of infrastructure has led to pulling down of India's competitive position in the global economy. For example, investment in production of computer hardware depends on a stable uninterrupted power supply. Due to lack of it, investors have refrained from investing in this industry.

Economic catalysts like supportive exchange rate policies, simplification of procedures, implementation of reforms at the state levels, etc., are some of the remedies for promoting the manufacturing sector in India.

Phenomenal amounts of cross-border transactions of money, due to lifting controls over capital mobility and technological advances have led to malpractices and speculation in financial markets. Scams have become the rule rather than an exception. Financial markets do not necessarily move according to the fundamentals of real economy or production. A more stringent legal regime is necessary to ensure that productive activities are at least rewarded as well as speculative activities, if not more. In enterprises where transparency is maintained and accountability is practiced, it inculcates confidence in the employees. Some of the success stories in Indian manufacturing sector have accepted precisely this strategy and we need to emulate it on a wider scale.

Other systemic factors undermining the performance of Indian manufacturing sector have to be addressed. These include: slackening of rural demand owing to low agricultural output/inequalities in income distribution; price competition from imports and erosion of competitive advantage of Indian exports; low levels and growth rates of productivity; slow down in general investment climate and sluggishness in capital markets.

There is evidence that the income inequalities in the Indian economy have increased during the nineties, relevant for market linkage of the sectors. The inequalities in distribution of incomes across states also have increased. The ratio of highest to lowest per capita State Domestic Product has increased from 2.52 (1985-86) to 3.70 (1999-2000). Price competitiveness of Indian exports has been eroded due to a faster rate of inflation in the Indian economy as compared with the other major trading partners and rivals in the global markets. The nominal external value of rupee fell by about 27 per cent during the period 1993-94 to 1999-2000. However, the general price level in India increased by about 40 per cent more than the price level in the trading partners. This indicates erosion of competitiveness of India's exports. At present the inflation rate currently in China is less than 1 per cent and that has to be the target inflation rate for India as well. Indeed, the major immediate catalyst for growth of Indian manufacturing industry would be the competition with China. It will save Indian manufacturing industry, just as competition with Japan has saved USA.

One of the best ways to gain competitiveness is through increase in productivity. Productivity growth, on an average, accounted for about half of the output growth in major developed countries whereas, for a group of developing countries it was 31 per cent (Chenery, Robinson and Syrquin, 1986). In India, the contribution of productivity has been hardly 20 per cent, during early 70s to late 90s. A high correlation between industrial production and infrastructure has been established by the Report on Currency and Finance (Reserve bank of India, 2000-1). A sharp decline in composite index of infrastructure since 1995 is visible except for some recovery in 2000. For example, the extent of power deficit range was about 7 to 11.5% during 1990-91 to 2000-1. We have also seen that it was the inadequate infrastructure, inter ailia, that pulled down the global competitiveness index of the Indian economy.

For a small open economy, global recession may not be a very important constraint. China has been able to increase her exports from 71 bn US $ (1991) to 266 bn US $ (2001) in the adverse global circumstances. As indicated earlier, price stability with high growth of manufacturing sector emerges as one of the necessary conditions for good export performance.

5 CONCLUSION

In a developing country like India, where over one fourth of population is still below the poverty line and inequalities in income distribution are increasing, the top priority would be to meet the commodity needs of the population while moving towards a global competitive edge. This is possible by promoting both agricultural and manufacturing sectors in a synergic manner, using innovative approaches that draw upon local resources: natural, intellectual and cultural. While the Western manufacturing industry is driven by aggressive power and intellectual property rights for local benefit, the Indian approach may embrace a more comprehensive approach based on emotional bonding and prosperity for everyone – a more responsible and sustainable approach in the long run. The common factors in either approach are however, the same: passion for manufacturing excellence and a global outlook. These in turn are characterized by system quality (zero complaints), cost competitiveness (zero waste) and delivery capability (zero delay) through appropriate technology and continuous innovation in products and processes. Achieving these is more of a mind game; success will crown only those who overcome complacency and a fatalist attitude prevalent in the society. Being a rare breed, such leaders of manufacturing need to be identified, trained, deployed and supported, and allowed to inspire others. The Government, academia and industry must work together to create a desire for manufacturing (*Kama*), facilitate its role in economy (*Artha*), leading to social development (*Dharma*) and eventually to global excellence in all spheres of life (*Moksha*).

REFERENCES AND DATA SOURCES

References

Ahluwalia, I.J. [1991], Productivity and Growth in Indian Manufacturing, Oxford University Press, New Delhi.

Ahluwalia, Montek, S. [2000], Economic Performance of States in Post-Reforms Period, Economic and Political Weekly.

Balakrishnan, P. and K. Pushpangadan [1994], Total Factor Productivity Growth in Manufacturing Industry: A Fresh Look, Economic and Political Weekly, vol. 29, pp. 2028-35.

Chakravarty, Sukhamoy [1998], Development Planning: The Indian Experience, 9th ed. New Delhi, Oxford University Press.

Chenery, H.,S.Robinson and M. Syrquin [1986], Industrialization and Growth: A Comparative Study, Oxford University Press, New York.

Gene Gregory [1986], Electronics and Technology: Enterprise and Innovation, John Wiley and Sons Publisher

Goldar, B.N. [1986], Productivity in Indian Industry, Allied Publishers Private Limited, New Delhi.

Homo Faber, Technology and Culture in India, China and the West from 1500 to the Present day.

Jerry Dermer, Competitiveness through Technology - What Business need from Government.

Keith Griffin [1990], Alternate Strategies for Economic Development, MacMillan Publisher

Rao, J. M., [1996a], Manufacturing Productivity Growth: Method and Measurement, Economic and Political Weekly, vol. 31, pp. 2927-36.

Rao, J. M. [1996b], Indices of Industrial Productivity Growth: Disaggregation and Interpretation, Economic and Political Weekly, vol. 32, pp. 3177-88.

Ryutaro Komiya, Masahiro Okuno, Kotaro Suzomora, Industrial Policy of Japan

Srivastava, Vivek [1996], Liberalization, Productivity and Competition: A Panel Study of Indian Manufacturing, Oxford University Press, New Delhi.

Srivastava, Vivek [2000], The Impact of India's Economic Reforms on Industrial Productivity, Efficiency and Competitiveness, Draft of the report Submitted to the National Council of Applied Economic Research, New Delhi.

Trivedi, P., A. Prakash and D. Sinate [2000], Productivity in Major Manufacturing Industries in India: 1973-74 to 1978-79, Development Research Group, Study No. 20, Department of Economic Analysis and Policy, Reserve Bank of India, Mumbai.

Data Sources

Annual Report, 2001-02, Reserve Bank of India, Mumbai

Annual Survey of Industries, Ministry of Planning, Government of India (various issues).

Economic Survey, Ministry of Finance, Government of India (various issues).

Global Competitiveness Report, 2001-02, (http://www.weforum. Org)

Handbook of Statistics on Indian Economy, 2001, Reserve Bank of India, Mumbai.

National Accounts Statistics, 2001, Central Statistical Organisation, Ministry of Statistics and Programme Implementation, Government of India

Report on Currency and Finance, 2000-01, Reserve bank of India, Mumbai.

World Competitiveness Yearbook, 2002, http://www02.imd.ch/ wcy

World Development Indicators 2001, CD-ROM, World Bank, Washington D C.

AUTHORS' PROFILES

Dr. Bhallamudi Ravi is an Associate Professor of Mechanical Engineering at IIT Bombay. Currently, he is also the coordinator of the Manufacturing group and a guest faculty in the School of Management. He completed his PhD from IISc Bangalore, winning the gold medal for the best thesis for industrial application. His current teaching and research focus includes intelligent casting design and web-based collaborative engineering. He works closely with manufacturing industry to develop software solutions; he has trained over 400 practicing engineers and guided several firms in exploring and adopting CAD/CAM technology. He has written over 50 technical papers and guided about 50 students. He twice represented India at World Foundry Congresses: Dusseldorf (1989) and Philadelphia (1996), and gave invited lectures in USA (including Ford Research Center), UK and Sweden. He is a member of several professional organizations and a regular reviewer for international journals, doctoral theses, books and research proposals.

Dr. Pushpa Trivedi is a Professor of Economics, Department of Humanities and Social Sciences at IIT Bombay. She completed her Ph.D. from University of Mumbai. She is recipient of Ford Foundation Post Doctoral Research Fellowship (1993-94) and during this fellowship was affiliated to Princeton University, USA. In 2002 she was awarded Visiting Fellowship by the Institute of Developing Economies (IDE) –Japan External Trade Organization, Japan (Jan 2002- July 2002). Her study on *Productivity in Major Manufacturing Industries in India: 1973-74 to 1997-98,* was sponsored and published by the Development Research Group, Reserve Bank of India. At IDE she worked on *Growth and Productivity in Selected Manufacturing Industries in India: A Regional Perspective*. Her major areas of research are: Economic Policies in India, International Trade and Finance and Environmental Economics. She has guided several research projects at doctoral and masters level, refereed articles for conferences and journals and doctoral theses.

Tadepalli Venkata Ravi Kumar is the Director of KRISAM Automation, with offices in Mumbai and Bangalore. He completed his B.Tech in Mechanical Engineering from IIT Madras and worked for ten years in Larsen & Toubro, Mumbai, in the Automation Department of the Switchgear division, before founding his own company. His team of ten engineers designs and manufactures a range of computer controlled machinery for factory automation, such as oil and glue dispensers, automatic assembly lines, and special machines for automatic welding applications. Their goal is to improve productivity and quality through innovative and sophisticated machinery developed for a specific client. Major clients include TVS Motor Co., Lucas TVS, Volvo, Sundram Fasteners, Larsen and Toubro, Schneider Electric and Minda.

Manish Jain completed his Masters degree in Computer Integrated Manufacturing in Mechanical Engineering at IIT Bombay, with a project at FIAT India Pvt. Ltd. for weight reduction of FIAT Palio car. His interests include reading and writing about economic and political affairs. He is also interested in Finance, especially in derivatives and options, and is a National Stock Exchange certified broker. He was the General Secretary Academic Affairs of the institute and was awarded the institute colour for his work. In his spare time, he involves himself in the institute drama events and has performed in inter collegiate festivals.

Manish Kumar Jalan completed his Masters degree in Computer Integrated Manufacturing in Mechanical Engineering at IIT Bombay, working on "Knowledge Management for Collaborative Engineering in Casting" for his dissertation. He has done an extensive study on corporate finance at IIM Ahmedabad and has worked on several projects with Geometric Software, Mumbai, a leading CAD/CAM software developer. His business plans like Mediserwiz.com and Jamboree Technologies, won many competitions at IIT Bombay (Eureka), IIT Kanpur (Megabucks) and IIT Delhi (Parivartaan). He has also held many organizational posts, including General Secretary of students and has won best office bearer and other prestigious cultural awards in the field of dramatics and organization. He is currently working in Aditi Technologies, Bangalore.

Rahul Gupta has also completed his Masters degree in Computer Integrated Manufacturing in Mechanical Engineering at IIT Bombay, and worked on "Weight Reduction of Fiat Palio" with FIAT India Pvt. Ltd. He currently heads Retro Labs Pvt Ltd, a telecom hardware company he started after graduation, that develops appropriate technology products for emerging telecom markets. He is an avid reader of business and economics journals and a strong supporter of Entrepreneurship, Innovation and Technology. He has held various organizational positions in the institute including the General Secretary of his hostel.