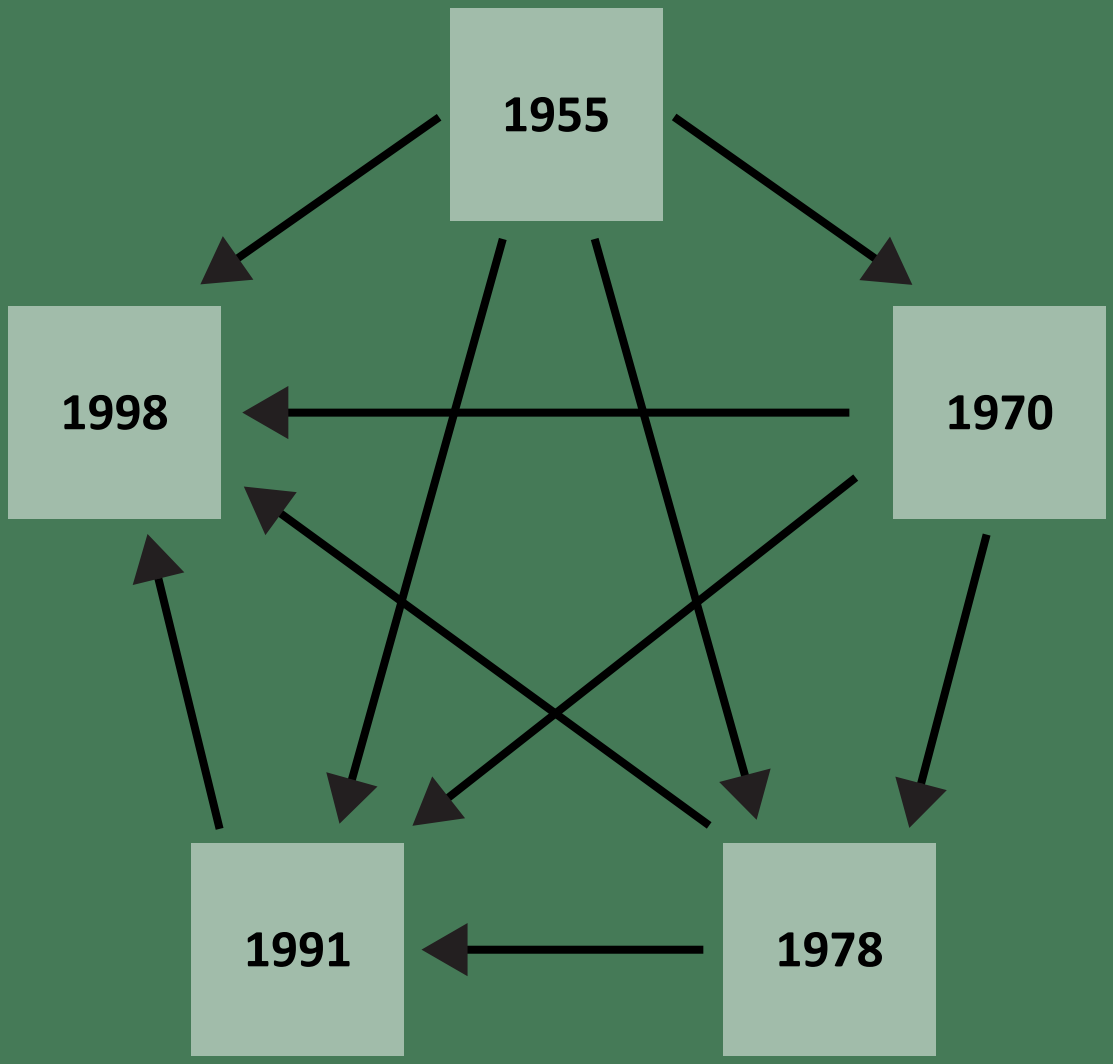
HISTORY OF COMPUTING IN INDIA (1955-2010)



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IEEE computer society

HISTORY OF COMPUTING IN INDIA

1955 - 2010

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SUPERCOMPUTER EDUCATION AND RESEARCH CENTRE

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As V.Rajarman describes in his preface, this document was written as a project of the IEEE Computer Society History Committee. It is made publicly available in this format as collaboration between the Computer Society and the author, who retains all rights while allowing this public version.

Sorel Reisman, Computer Society 2011 President, originally suggested this project to the History Committee. The committee is grateful V.Rajaraman agreed to join the committee and carried out this valuable historical research.

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PREFACE

In January 2011 David Walden, Chairman of the History Committee of the IEEE Computer Society, sent a mail to me and asked whether I would be willing to be a member of the committee. I am not a professional historian but have some interest in the history of computing, having grown up with the field for over five decades. I agreed to join the committee. Dave subsequently enquired whether I would be willing to write a report on the history of computing in India. I agreed with some trepidation as I am an amateur in this area. But once I started collecting material and reading it I got involved. I estimated that I would take about three months to write the report. It was a gross underestimate. It took me almost six months. As I never kept a diary I had to rack my memory to remember various important events and cross check them with my colleagues. I had given an invited talk at the IT.com Conference in Bangalore in 1999 and wrote a short paper based on that talk titled "Information Technology in India - A Retrospective (1965-1999)" in the Communications of the Computer Society of India. That paper provided a skeleton outline for this report. I expanded it to cover the period 1955 to 2010. The Internet provided a mine of information besides the two books on the history of IT in India by (late) C.R.Subramanian and Dinesh Sharma. The first draft of this report was ready by mid August 2012. I sent it to a large number of professionals in India and to David Walden who sent it to two other members of the History Committee. Based on the perceptive comments of all these reviewers, I re-wrote many parts of the report and corrected a number of errors. The report is much longer than what I planned but I do hope that it is reasonably comprehensive.

I would like to sincerely thank the following reviewers (in alphabetical order) who read the report in the midst of their other commitments and gave me numerous suggestions for improving it: S.Bhatnagar, P.C.P.Bhatt, H.K.Kesavan, R.Krishnamurthy, F.C.Kohli, H.N.Mahabala, S.K.Nandy, N.R.Narayana Murthy, Anand Parthasarathy, T.Radhakrishnan, N.Ramani, S.Ramani, P.V.S.Rao, Andy Russell, Veer Sagar, N.Seshagiri, Dinesh Sharma, Lalit Shawney, Om Vikas, and Jeff Yost.

David Walden, apart from initiating me into this project, read my report meticulously, pointed out many errors, and improved the style of my presentation. Besides these, he also refined the cover design of this report. I thank him for spending his precious time and the interest he has taken to improve this report.

Special thanks are due to T.Dhanapal who has a doctorate in English and readily agreed to edit my manuscript and improve its style. I thank my wife Dharma who proofread the manuscript and pointed out a number of errors and

suggested changes in the style of presentation. Thanks are due to Ms.T.Mallika who did an excellent job of word processing and provided secretarial assistance.

I have not taken all the suggestions given by the reviewers to whom I sent the manuscript as it would have considerably increased the size of the report. I take full responsibility for the final report, the style of my writing, and the opinions expressed in it.

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History of Computing in India – 1955 to 2010

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Abstract

In this report I have traced the history of computing in India from 1955 to 2010. I have identified four break points in the historical development, each breakpoint caused by changes in the political climate and consequent changes in the government policies on the development of computers.

The initial period 1955 to 1970 was a period of exploration with no specific government policies guiding this technology. However, there were a number of initiatives taken in education such as the establishment of the Indian Institutes of Technology and also starting the design and production of computers. The Bhabha Committee appointed by the Government of India in 1963 realized the importance of electronics and computers in national development and suggested establishment of the Department of Electronics (DoE) in the Government of India (GoI) to promote rapid growth of electronics and computers. This department was established in 1970 and was the first breakpoint.

From 1971 to 1978 the DoE laid stress on self-reliant indigenous development of computers and a company called the Electronics Corporation of India Ltd. (ECIL) was financed to design, develop and market computers using primarily components made in India. ECIL made computers called TDC 312 and TDC 316 which were similar to the PDP series computers made by the Digital Equipment Corporation of the USA. The DoE also initiated many Research and Development (R&D) projects with assistance from the United Nations Development Programme (UNDP).

The second break point came in 1978 after the government led by the Congress party was defeated in 1977. IBM which was at that time refurbishing obsolete 1401 computers in India was asked by the government to reduce equity, to take an Indian partner and to manufacture IBM 360 series computers. IBM refused and closed its operations in India in 1978.

The new government decided to open up computer manufacturing to the private sector and a number of companies started making minicomputers using imported microprocessors. UNIX was the Operating System of choice. In 1984

and 1986 the government removed numerous controls on the industry and on imports when Rajiv Gandhi became the Prime Minister. The new policy allowed the import of fully assembled motherboards with processors and reduced import duties. This led to a sharp reduction of price and a speedier spread of computer use. In 1986 software companies were allowed to import computers at reduced import duty rates to enable them to export software. Software development was recognized as an industry deserving many tax concessions. The year 1986 also saw the change in the mind-set of the general population and the politicians about the relevance of computers due to the success of the computerized ticket reservation system of the Indian Railways. The new reservation system reduced the waiting time in queues of customers wanting to reserve seats on trains. It also reduced some malpractices and led to an increase in the number of reservation clerks as a large number of counters were opened, each one requiring a clerk.

The third break point came in 1991 when India was about to default on the payment of foreign debt. The country was bailed out by the International Monetary Fund (IMF) which forced India to open its economy and reduce controls on the local manufacturing companies. Software and software services companies formed the National Association of Software and Services Companies (NASSCOM) which successfully lobbied with the bureaucrats and the politicians and obtained many tax and other concessions. One of the major initiatives taken by the DoE at this time was the establishment of Software Technology Parks (STPs) with satellite communication links which enabled Indian software companies to develop software applications on their international clients' computers from India. Indian software companies also took advantage of the Y2K and the Euro conversion opportunities to modify and improve a large number of legacy software systems. They also became quality conscious and obtained the quality certificates issued by the International Standards Organization (ISO) and the Capability Maturity Model (CMM) certificate issued by the Software Engineering Institute (SEI) of the Carnegie Mellon University, USA. The emphasis of the government policies shifted to promote software services companies as their exports grew.

The fourth break point came in 1998 when the new government under Atal Bihari Vajpayee declared "IT as India's tomorrow", and took a number of proactive measures to promote software companies. An IT task force was appointed to recommend changes in the policies of the government. Measures were taken to give a tax holiday on the export earnings of the Indian software services companies for ten years and import duty was exempted on computers and software packages imported for exporting software. Multinational companies were welcomed to set up software development and Research and Development (R&D) centres. Software and services exports grew rapidly from USD 2 Billion in 1998 to USD 50 Billion in 2010. Information Technology was

contributing 6.4% of GDP in 2010 and was providing employment to 2.4 million software professionals.

It is concluded that the initiatives taken by the government in the late 70s to promote education in IT, setting up of R and D centres and funding a large number of research projects with the assistance of the United Nations Development Programme (UNDP) provided the human resources which enabled the IT industry to grow. The initiatives taken by software companies to put in place systematic processes for software development, achieving quality certification and gaining expertise in project management enabled them to face international competition and obtain application software development and services contracts from the West. Even though the initiative taken by the Government of India in the 70s to establish a self-reliant hardware industry in the public sector was not successful, it provided the confidence and the human resources which catalyzed the growth of the private hardware and software industry in the 80s and the 90s.

1. INTRODUCTION

The computer age in India began in 1955 with the installation of HEC-2M (a computer designed by A.D.Booth in England) at the Indian Statistical Institute (ISI) at Calcutta (now Kolkata) [1]. The same year a team headed by R.Narasimhan started designing and fabricating a computer at the Tata Institute of Fundamental Research (TIFR) at Bombay (now Mumbai) 2000 km away on the west coast of India [2]. In 1955 only a few dozen scientists and engineers in India knew about computers. In 2010 there were over 2.4 million people employed in computer related jobs and over 60 million Personal Computers were in use. Information Technology which depends on computers contributed 6.4% of the GDP of India and IT services became the fastest growing segment among export industries and grew by 22.7% in 2010 with aggregate export revenue of USD 50 billion and domestic revenue of USD 17 Billion [3]. Undoubtedly it has been an exciting journey from 1955 to 2010 though not smooth and steady. In the 60s and the 70s there was a lot of trepidation about the use of computers and their impact on employment. Questions were asked whether computers were relevant for an over populated poverty stricken country. From this jittery beginning India reached a stage in 1998 when its Prime Minister Atal Bihari Vajpayee could declare IT as "India's Tomorrow". How did India reach this state? What were the contributing factors? What lessons did India learn? In this report I will try to answer these questions.

The development of computing in India is inextricably intertwined with two interacting forces: the political climate (determined by the political party in power) and the government policies mainly driven by the technocrats and the bureaucrats who acted within the boundaries drawn by the political party in power. There were four **"**break points" in the development of computers and their applications in India caused by the political party in power and some external forces. These break points are those significant events in 1970, 1978, 1991 and 1998 that changed the direction of the development of computers and their applications (namely, Information Technology or IT) in India. In this report we will explain why these breaks occurred and how they affected the growth of IT in India. The period 1955 to 1970 saw the beginning of the use of computers in India. A committee under the chairmanship of Homi Bhabha, an atomic scientist, realized the importance of electronics and computers in India's development and suggested the establishment of a separate government department to promote its planned growth. Consequently a separate Department of Electronics (DoE) was established in 1970 by the Government of India. The period 1970 to 1978 saw a slow controlled growth of computing in India. During this period the political class had genuine doubts whether computer technology was relevant for a poor developing country. However, this did not impede the technocrats and the educators from laying the required

foundation which was essential for the future growth of Information Technology. The period 1978 to 1990 saw the emergence of a local computer manufacturing industry in the private sector and the gradual loosening of government control over the computer industry. The period 1991 to 1997 saw "economic liberalization" in India which abolished tight government controls in a number of areas that encouraged the private IT entrepreneurs to innovate. Import of computers was liberalized and foreign collaboration and investments were permitted which enabled a large number of software companies to export software services. In 1998 the government took proactive steps to promote Information Technology by giving incentives such as tax breaks and reduced import duties. Communication infrastructure also improved. The cost of computers came down. All these resulted in a rapid growth of the software services industry with annual growth rate exceeding 30%. We will identify the significant events during each of the above referred periods and explain their impact on the development of IT in India.

A number of studies on various aspects of the development of computers in India are available in the literature. The book "The Long Revolution – The birth and growth of India's IT Industry" by Dinesh C.Sharma [4] gives a detailed account of the history of IT in India from a journalist's perspective. In an earlier book C.R.Subramanian [5] discusses computer technology in India before 1990. It is more technical with detailed statistics and excerpts from government archives. The book highlights the weaknesses inherent in the government policy of planned development of computers.

Ramesh Subramanian [6] traces the history of Information Technology in India by "gathering evidence" by talking to five IT professionals representing different groups – namely the government, education, research and industry. (I was not one of them). J.M.Grieco [7] analyses how India negotiated with the International computer industry to preserve its national interest without becoming subservient to multinationals. Balaji Parthasarathy [8] discusses how India's domestic policy initiatives enabled the Indian software industry to grow rapidly. Ross Basset [9] analyses the impact of computer education initiatives taken by IIT, Kanpur and other IITs and how this mutually helped India and the USA. P.Walcott and S.Goodman [10] document the growth of computer networks in India from 1980 to 2003. V.Rajaraman [11] has given a brief retrospective of IT in India during the period 1965-1999. The first part of the book "Homi Bhabha and the Computer Revolution" edited by R.K.Shyamasundar and M.A.Pai [12] (published to commemorate the birth centenary of Homi Bhabha) has five articles that present a historical perspective on the development of computer technology in India by professionals who participated in the development. It has other articles written by the pioneers of the Indian computer and communication industry and provides a wealth of "first hand" material.

The only comprehensive and readable history of IT in India is by Sharma [4], a journalist, who interviewed a number of individuals (including me) who participated in the development of IT in India. To the best of my knowledge no short report has been published on the history of IT in India, identifying break points, why they occurred and how they changed the slope of growth. As an educator, a policy maker in government and a consultant to IT industry during its formative years, I had the unique opportunity of participating in and observing the growth of IT in India from 1962 till date. This report will thus be coloured by my experience and opinion.

This report is divided into 8 sections and 2 appendices. The next section presents some facts about India as background information. Section 3 describes the historical developments of computing in India during the years 1955 to 1970 starting with the installation of the first computer in 1955 culminating in the decision to establish a Department of Electronics by the Government of India to oversee a planned growth of electronics and computers. This is followed by section 4, which describes the self-reliant growth of the computer industry in India during 1970-1977. During this period the DoE funded the computer division of a public sector company, called the Electronics Corporation of India Ltd. (ECIL), to manufacture computers. Section 5 describes the growth of private enterprise in both hardware design and software development between 1978 and 1990. This period began with IBM's withdrawal from India following which a number of local private entrepreneurs started to manufacture minicomputers. In this section I also describe how software services industry started and grew. Section 6 covers the period 1991 to 1997 during which India liberalized its economy, dismantled controls on industry, allowed foreign companies to enter India and promoted the growth of software services industry by taking numerous favourable policy initiatives. By 1997 the software services industry was on course towards rapid growth. Section 7 describes the period 1998 to 2010 which saw the rapid growth of the IT industry. It explains the political environment and the policy initiatives which led to this rapid growth. The report concludes with section 8 which discusses the lessons learnt from history. It is concluded that the investments and the initiatives taken by the government in education, research and development projects, liberalizing and improving communications and supporting private software services industries with a number of incentives paid rich dividends. Investments in public sector manufacturing of computers, however, did not yield commensurate results. There are two appendices which are useful in following this paper. Appendix 1 gives a time line of development of computers in India. This gives a bird's eye view of history. As the development of computing in India is strongly influenced by the political climate and government policies, Appendix 2 gives a time line of the political and economic history of India.

2. SOME FACTS ABOUT INDIA

India is a study in diversity. From the towering Himalayas in the north, through the fertile plains fed by the Ganga and Yamuna, to the Deccan Plateau and the lush green coast of the southern peninsula the geography is diverse. As one travels from North to South and East to West one encounters people talking in twenty-two different languages and hundreds of their dialects. It is also the home of seven major religious groups – Hindus, Muslims, Christians, Sikhs, Jains, Buddhists, and Zoroastrians. It is the second most populous country in the world with a population of 1.2 billion. It is an old civilization but a young country – the median age of an Indian is 26.2 years. It is the seventh largest country in the world (about a third of the size of the USA). Seventy percent of its population lives in 600,000 villages with only 30% living in the cities. It is the largest democracy in the world with universal adult suffrage and a voting age of 18. There is a vast disparity in income levels with many billionaires coexisting with a quarter of the population surviving on less than Rs.100 (USD 2) per day. The country is a federation of 28 states and 7 Union Territories. The states are constituted on linguistic basis except in the northern plains where Hindi is used widely. India has a written constitution and a political system modelled after the British with a directly elected Lower House (Lok Sabha) and an indirectly elected Upper House (Rajya Sabha). The central government controls most of the revenue and fixes the financial outlay of the states. It also controls defence, foreign relations, communications, and Information Technology and controls education jointly with the states. India has a planned economy with five year planning horizon. The legal system is similar to the British system. The Supreme court has the power to review laws passed by the parliament to ensure that they adhere to the constitution.

India has adopted a mixed economy – a number of public sector companies control oil, natural gas, defence production, and heavy industries. Currently there is a thriving private sector. Information Technology, automobile production, pharmaceuticals, communications, and retail trade are dominated by the private sector. Privatization of major industries began in the early 90s. Economic growth rate was slow (around 3.8% of the GDP) for the first 30 years after independence in 1947 but has been above 7% since 2002. Its current GDP (based on purchasing power parity) is USD 4 trillion – the fifth highest in the world [13] but the GDP per capita is only USD 3500. The country faces long term challenges – inadequate physical and social infrastructure, widespread poverty, wide disparity in quality of education offered, limited rural employment opportunities, and wastage in government spending.

Communication facilities in India have improved rapidly since the mid 80s. Currently India has over 40 million land lines and 850 million mobile phone subscribers. During 2010-11 mobile phone subscriptions increased at the rate of

15 million per month! India builds its own satellites and launches them. At present there are 11 INSAT communication satellites in service and over 110,000 VSATS (Very Small Aperture Transceivers) have been installed. Unlike the deep penetration of mobile phones, that of the Internet is limited. Although the number of Internet users is estimated to be around 100 million (the third largest in the world) the reach is only about 8.4% of the population. The number of PCs is estimated to be around 60 million with the growth rate of 15% per year. The number of fixed line broad band connections is estimated at 6 million [14].

Another interesting fact about India is the distribution of population. It is estimated that over 60% of the population is in the age group of 15 to 59 [15]. By 2020 India will have the largest working age population in the world. A big challenge will be to find gainful employment for this vast population.

Even though Hindi, spoken by over 40% of the population, is the official language, English which was introduced by the British continues to be the language used by the government and the judiciary. The medium of instruction in science and engineering courses in colleges is also English. The exact number of people in India who use English is difficult to arrive at but it is estimated that the persons with a working knowledge of English is 125 million (the second largest in the world after the USA). The total circulation of English daily newspapers is estimated to be 30 million (incidentally The Times of India is the largest circulated English language daily newspaper in the world – 13 million copies per day) [16].

The large number of English speaking persons in the age group 20 to 50 (estimated to be over 50 million) has led to a number of services from the western countries to be outsourced to India. The number of students attending colleges has grown rapidly since independence. Currently India graduates around 1.3 million engineers per year with 32% in Computer Engineering and IT from about 3000 colleges [17]. The quality of graduating students is not uniformly good. Whereas the graduates of the IITs and the NITs (around 10,000) are excellent, industry employers opine that the graduates of other institutions are not employable as soon as they graduate and need further training.

As pointed out earlier India is a democracy. Except for 3 years during which there was an authoritarian rule, India has had a democratically elected central government. Congress, the major political party, governed India from 1947 to 1972. After that there have been several coalition governments at the centre. The state governments are ruled by different political parties (many of them confined to only one state). The central government is strong and all major policy initiatives relating to electronics, communication, and information technology are taken by it. The history of the development of computers in India is inextricably linked to the political history of India. As a democracy any major

policy change requires building consensus. This is a slow process particularly when it is coupled with a vocal free press and electronic media. The country is transforming from an agricultural economy to a manufacturing and service economy. Manufacturing, particularly in electronics, has been stunted due to many reasons such as lack of investment and archaic labour laws. The software services industry requires less capital and is not encumbered by archaic labour laws. This is probably one of the reasons for its rapid growth.

Economy of India

When India became independent from Britain in 1947, the Congress party which spearheaded the independence movement assumed power and later won the general elections. Jawaharlal Nehru became the first Prime Minister. His dream was to make India a social democracy with a mixed economy, namely, the co-existence of private and state enterprises. His government which believed in planned development, similar to that of the Soviet Union, constituted the Planning Commission with the Prime Minister as its ex-officio chairman. The primary function of the planning commission was and continues to be the drafting of five year plans for the growth of various sectors of the economy and to allocate resources [18]. Major industries such as steel, railways, electrical power, and communications were reserved for the public sector. The first five year plan started in 1951. A budget of Rs.235 billion was allocated (exchange rate 1 USD = Rs.4.5 in 1951). The emphasis in this plan was on agriculture and irrigation. The second five year plan (1956-61) was drafted by Mahalanobis, a well known statistician. The outlay was Rs.480 billion and the emphasis was on heavy industry. Five steel plants were established in the public sector and large hydro-electric projects were initiated. Mahalanobis' economic model was a closed one with emphasis on self-reliance. The Directorate General of Technical Development of the Government of India drafted plans to support manufacture of all varieties of items, for example, electric goods, plastics, electronic items, chemicals, etc. It specified quantities to be manufactured and whether they were to be made by the public sector or the private sector and, if private sector, whether by small scale industries or by larger industries. Licences were granted for specified quantities. Even the locations of the manufacturing units were specified so that the industry was distributed evenly throughout the country. A large number of items were reserved for the small scale sector. For example, electrical items such as plugs, sockets, wires, etc., were reserved for the small scale sector. However, as this sector lacked capital and the quantity to be manufactured was restricted, the quality of products was poor and the cost high. It was "protected" by the ban on import of goods which were locally manufactured. The idea was to provide employment and to promote self-reliance. However, this policy led to the manufacture of shoddy, non-standard items. For example, unless the plug and the socket were bought from the same manufacturer they would not fit. (Even today the problem persists.) The just

described period in the economic history of India, between 1947 and 1990 during which elaborate rules were to be followed by entrepreneurs to obtain licences and permits issued by government officials to start industries, today (post liberalization in 1991) is derisively called “Licence-Permit Raj”. (Raj is a Hindi word for government; see Wikipedia [78] for an essay on “Licence-Permit Raj”.) Collaboration with foreign companies was permitted on a case by case basis.

Planning also has some very good features. The first plan realized the importance of higher technical education and five Indian Institutes of Technology (IITs) were planned. Government also gave scholarships to a number of meritorious students to study abroad or get practical training in industries. Later the government also set up Regional Engineering Colleges (REC) (one in each state of India) to provide good quality technical education. (RECs have now been renamed National Institutes of Technology, NITs.)

Another problem India faced was a balance of payments deficit. Setting up of heavy industries demanded imports and most of the required petroleum products had to be imported. Exports comprised mostly raw materials such as cotton and minerals. There was dearth of foreign exchange (i.e., hard currency such as US Dollars or UK Pounds earned through export) which dictated many of the policies of the government. Any private industry requiring import using scarce foreign exchange was subjected to close scrutiny. A company was required to earn foreign exchange through export to make up for the import.

3. LAYING THE FOUNDATION (1955-1970)

Jawaharlal Nehru, the first Prime Minister of India, had great faith in science and technology as engines of growth. He was convinced that India required rapid industrialization to reduce the abysmal poverty of its people. The parliament of India passed the Scientific Policy Resolution in 1958, the full text of which may be found in [19]. It has a preamble which among other clauses states that

> "Science and technology can make up for deficiencies in raw materials by providing substitutes, or, indeed by providing skills which can be exported in return for raw materials. In industrializing a country, heavy price has to be paid in importing science and technology in the form of plant and machinery, highly paid personnel and technical consultants. An early and large scale development of science and technology in the country could therefore greatly reduce the drain on capital during the early and critical stages of industrialization"

and concludes with several aims of the scientific policy among which two important aims are:

> "To foster, promote and sustain by all appropriate means, the cultivation of science, and scientific research in all its aspects - pure, applied and educational"

and

> "to encourage, and initiate, with all possible speed, programmes for the training of scientific and technical personnel, on a scale adequate to fulfill the country's need in science and education, agriculture and industry, and defence".

3.1 EARLY COMPUTER INSTALLATIONS

Nehru's confidants, P.C.Mahalanobis and Homi J.Bhabha, influenced policy making in government. Mahalanobis was a renowned statistician and Bhabha a well known atomic scientist. Mahalanobis founded the Indian Statistical Institute (ISI) in Kolkata in 1931 and Bhabha the Tata Institute of Fundamental Research (TIFR) in Mumbai in 1945 and later the Atomic Energy Establishment in 1949. Both the scientists realized the importance of computers in scientific research and statistical calculations. Mahalanobis formed a small computer group at the ISI and ordered a computer from the British Tabulating Machines (BTM) which was marketing in India keypunch machines, sorters and mechanical calculators. BTM agreed to sell a computer to the ISI in 1954 though without any technical support. The ISI was to install and maintain the machine using its own scientists and engineers. The ISI sent Mohi Mukherjee and Amresh Roy to England in December 1954 [1]. A computer HEC-2M (Hollerith Electronic Computer Model 2M) was being designed by A.D.Booth at Birbek College, London, and assembled in BTM's workshop in London. Mukherjee and Roy observed the design and assembly of the computer and gathered requisite information to effectively use and maintain the machine to be installed at the ISI. The computer was ready in June 1955 and arrived in Kolkata in July 1955 without

any manuals. Mukherjee and Roy installed and tested the machine at the ISI using their notes and it started working in August 1955 [1]. HEC-2M had a drum memory with 1024, 24 bit words and had to be programmed in machine language. It had punched card I/O and a printer. Programs were written using machine language in binary code. Around a dozen people learnt to program the computer which was used for some statistical calculations. Around the same time a group led by R.Narasimhan at the TIFR, Mumbai started designing a "pilot" computer. It was primarily to see if they could design logic circuits and systems with vacuum tubes. It was completed in 1956 [2]. In 1957 the group started designing a full scale computer. The control logic design of the TIFR computer benefited crucially through design details made available by the ILLIAC team of the University of Illinois [2, 20]. The group at TIFR designed a 2048, 40 bit word core memory (15 micro seconds cycle time), an arithmetic unit with some innovations [21], a paper tape I/O and a Cathode Ray Tube output unit. The machine used 2700 tubes and 1700 germanium diodes and 12500 resistors. It was completed in 1959 and commissioned in 1960. It was installed at the new building of TIFR in 1962 and named TIFRAC (TIFR Automatic Calculator) by Jawaharlal Nehru. Being a machine using vacuum tubes it was a power guzzler, consuming 20KW. An assembler was written for it. It was used effectively for solving numerous physics problems in-house. It was also used by the scientists of the Atomic Energy Establishment and some Universities. It proved that Indians could design a computer and use it effectively. TIFRAC also created a core group of engineers who could maintain computers and understood system programming. An assessment of TIFRAC and its impact may be found in [20].

In the meanwhile at the ISI, Kolkata, HEC-2M was found to be a very difficult machine to use. Mahalanobis started scouting for another machine. It was difficult to get funds, particularly foreign exchange funds. He negotiated with the USSR and a URAL-1 computer was ordered in 1958 with assistance from the United Nations Trade Assistance Program. URAL-1 was also a first generation machine using vacuum tubes and had a drum memory, punched tape I/O and a magnetic tape [22]. It had 40 bit words, and could perform 12000 operations per second and was primarily used for statistical calculations. It was installed by the Russian engineers. All the manuals were in Russian and the ISI engineers learnt Russian to enable them to maintain the machine. In 1958 the ISI was the only institution in India with two working computers and a group who could program and maintain them. ISI was the de-facto National Computer Centre used by other universities, atomic energy establishment and defence research laboratories.

When TIFRAC was inaugurated in 1960, ISI decided to build a second generation digital computer using transistors. A project was started jointly with Jadavpur University, Kolkata, to design this machine. It was completed in 1966 and named

ISIJU. It was not a successful project as the computer was unreliable and did not have appropriate software [23].

After the completion of the TIFRAC project R.Narasimhan went to the University of Illinois during 1961 to 1963 and did pioneering research in picture processing [24]. TIFR soon realized that commercial companies were surging ahead in designing computers and it was prudent to buy rather than build a computer for use by researchers in India. A committee headed by R.Narasimhan evaluated various machines and selected the CDC 3600-160A, a computer manufactured by the Control Data Corporation, USA, as an appropriate computer for scientific computing at the TIFR. It was a bold decision as CDC 3600 was not yet a commonly used computer in 1963 [25]. The system was bought for USD 1.5 million with funds provided by the United States Agency for International Development (USAID). (Homi Bhabha was able to convince the Government of India to arrange for the funding.) It was installed at the TIFR in mid 1964 [20]. It was the first high performance machine installed in India and was one of the best computers of its generation. The CDC 3600 had 32K, 48 bit words and a full set of peripherals. TIFR sent engineers for training to CDC in the USA to maintain the machine. CDC assisted in installation and early maintenance but later maintenance was done in-house by TIFR. Over 150 institutions from all over India used it effectively for numerous large scale number crunching problems [20] for more than a decade.

Another computer installed early in India was an IBM 1620 in August 1963 at the Indian Institute of Technology, Kanpur (IITK). It was the first computer with a FORTRAN compiler to be installed in an educational institution in India. The IBM 1620 was imported with financial assistance of the United States Agency for International Development (USAID) which channelled the funding through the Kanpur indo-American Program (KIAP). KIAP was a consortium of nine major US Universities which assisted establishment of the IIT at Kanpur by sending visiting faculty members and by assisting in the purchase of equipment [9, 27]. One of the major decisions taken by KIAP was to install a computer at IITK. In 1963, the IBM 1620 was a popular computer used by a number of universities in the USA. It was a small digit oriented computer with a 60K digit main memory, three tape drives and a punched card reader/writer. The punched outputs as well as programs punched on cards were printed with an IBM 407 accounting machine. Besides this there were 20 key punch machines. The IBM 1620 was installed and maintained by IBM engineers (Indians trained by the IBM).

KIAP sent Harry D.Huskey of the University of California, Berkeley, and Forman S.Acton and Irving Rabinowitz from the Princeton University to educate the faculty and students of IITK on using the computer. As soon as the IBM 1620 started working a ten day intensive course on programming for the faculty of IITK was designed by this group. Huskey took a proactive step and instead of

restricting the course to IITK faculty, he invited scientists, engineers, and the faculty members of other institutions in India to attend the course. Each course had around 60 participants who were given hands on experience in FORTRAN programming and numerical methods. These courses which started in 1963 were conducted thrice a year. The course was so popular that it was continued till 1975 by the IITK faculty after the American Professors left in 1965. Over 1500 scientists working in a number of Universities and research laboratories were trained. IITK also pioneered by introducing in 1964 a compulsory course in programming and numerical methods to all engineering students. The IBM 1620 was used 24 x 7 and all students had free access to it. Soon the IBM 1620 was saturated and IITK bought an IBM7044 in 1966 (with funds provided by the Government of India). Details of the contribution of the IIT at Kanpur to the development of information technology in India may be found in [9, 26, and 27].

The first commercial computer to be installed in India was an IBM 1401 at ESSO Standard Eastern Inc., an oil marketing company in Mumbai. Between 1961 and 1964 twelve computers were installed in Research and Development organizations and two in educational institutions [28].

3.2 COMPUTER MANUFACTURE

Other than the Scientific Policy Resolution which broadly laid down the policy to promote modern technology, there was no government policy on computers. As part of the five year plans higher technical education was promoted and five Indian Institutes of Technology and 13 Regional Engineering Colleges, one in each state, were established. The Directorate General of Technical Development and the Department of Defence Supplies controlled the area of computers. Foreign companies were permitted to manufacture and sell computers provided foreign exchange was not required. Computers were not considered a priority area that deserved foreign exchange outflow. IBM of the USA and the British Tabulating Machines (which was later named International Computers Ltd., ICL) were already selling mechanical unit record equipment, namely, key punches, verifiers, sorters, tabulators and accounting machines to a large number of companies, the Indian Railways, and statistics departments. They wanted to sell their latest electronic replacements. As was mentioned earlier IBM sold a 1401 computer in 1961 to ESSO, an American oil marketing company operating in India. It served as a showpiece to prospective customers. As import of computers using foreign exchange was difficult IBM and ICL applied for licences to manufacture computers in India. IBM was more aggressive and proposed to the Government of India that it would manufacture mechanical key punch machines (model 029) using 80% local components and export them and earn foreign exchange. IBM requested permission to import used computers to the extent of 80% of the foreign exchange earned and market them after refurbishing them [29]. IBM chose the 1401 data processing machine as suitable

for their operations. This was in 1965 when a large number of IBM 1401s were being replaced by the System/360s in the USA and Europe. IBM's business model was to import used (or As Is) IBM 1401 computers at a so called inter-company billing price which was quite low as they were used machines whose book value was low. Thus for the foreign exchange entitlement based on export of key punch machines they could import many IBM 1401s. The used 1401 computers were dismantled in a factory in Mumbai, the worn out parts were replaced, and the machines were reassembled, painted and rented to customers in India. Besides manufacturing 029s and refurbishing 1401s, IBM also manufactured paper board cards for use in their card punching machines.

By 1970 the IBM 1401 was the most popular computer in India with 80 installations. (In 1964 IBM introduced System/360 in the USA. In 1971 the IBM 1401 was phased out in the USA.) The annual rental charged for a high end 1401 (i.e., one with 4 tapes and 2 disks) was around Rs.850,000 (USD 190,000 at the prevailing exchange rate). IBM was in fact accused of profiteering, as the rental in the USA was much lower. In its defence IBM asserted that the rental included free maintenance and the services of a systems engineer who often analyzed the data processing requirements of the organization, designed the software system and even assisted in programming. In other words IBM maintained that it was selling a computing service rather than just renting a computer. To the credit of IBM it should be said that its service was excellent and it recruited and trained very good technical and sales persons. A whole generation of maintenance engineers and programmers were trained and nurtured by IBM. In short IBM set a bench mark for professional operations in India [30].

In comparison to IBM its rival International Computers Ltd., a British company which was marketing ICL 1901A computers, had a market share of only 48 machines which were assembled between 1965 and 1975 by Bharat Electronics Ltd. (BEL), a public sector company [31]. IBM 1401s were everywhere. Indian Railways had over a dozen, most Tata group companies and textile giants had them. The first computer at the Tata Consultancy Services was an IBM 1401 and even the ISI had installed an IBM 1401. IBM was also running data centres in major cities to cater to smaller companies which could not afford to rent a 1401 by themselves. By 1970, IBM had around eighty 1401s installed in India. Besides locally assembled 1401s, IBM had also sold a 1620 and a 7044 to IIT/Kanpur and one 1620 each to Delhi University, Roorkee University, Ahmedabad Textile Industries Research Association, Defence laboratories and Physical Research Laboratories at Ahmedabad.

4. SELF-RELIANT GROWTH OF THE COMPUTER INDUSTRY (1970-1977)

During the 1950s electronics was not considered an important industry by the Government of India and there were no specific policy initiatives. As we saw, IBM and ICL had assembly operations in India and dominated the Indian computing scene. After the border skirmish with China in 1962 it was realized that electronics and communications were important in defence preparedness and for long range industrial growth of India. The Government of India constituted a committee in 1963 with Homi Bhabha (Chairman of the Atomic Energy Commission) as its chairman to examine the area of electronics in depth and prepare a plan for its development. The Bhabha Committee on Electronics had its report ready by 1966 [32]. Unfortunately Bhabha was killed in an air crash before formally submitting the report. One of the main recommendations of the report was to establish a Department of Electronics (DoE) in the central government to promote electronics and computer industry. It also suggested the constitution of an Electronics Commission (EC) with wide financial and executive powers to take quick decisions to promote electronics.

The Bhabha committee constituted a subcommittee on computers chaired by R.Narasimhan which projected the demand for various types of computers for the next ten years [33]. The committee recommended setting up one very large computer to be imported for a national facility and 3 to 5 medium large computers to be imported and established as Regional Computer Centres (RCCs). It also recommended that the RCCs be operated as shared computing facilities like power utilities. It recommended that all smaller computers should be manufactured locally using local components. It estimated the number required as around 500 per year for the next 10 years.

The Bhabha Committee report was discussed by a large group of participants from educational institutions, companies, government, R&D laboratories and defence forces in a National Electronics Conference held at TIFR, Mumbai, in 1970. In that conference the Bhabha Committee report was debated. I attended this conference and opined that [34]:

> "Any strategy (for indigenous design and development of computers) should take into account the genius and resources of the country. We do not have a large enough internal market of sufficient volume to justify the chronological development:
>
> components → circuits → systems
>
> We should go backwards and design systems first and import the needed components. If the design and the product ideas are good, it will pay enough dividends by export to sustain necessary imports and break the vicious circle of system obsolescence due to component obsolescence. Foreign exchange can also be earned by software export."

However, my comment was not taken seriously. Vikram Sarabhai (who succeeded Homi Bhabha) and chaired the conference opined at the concluding session that [35]:

> "I think that this field (of computers) is far more fundamental, of wider significance than any other field of electronics. It is an all pervasive way of thinking, looking at problems and analyzing, and it is of particular relevance to our developing country where resources are scarce, where we want to optimize to produce the best results from minimum resources".

He went on to say that

> "I do believe that major international companies have a contribution to make in India, on honourable commercially rewarding terms, on ground rules which are acceptable to India. I do not think that this could be at the cost of a major national effort, which we must put out without further delay."

Based on this thinking the Government of India started a computer division in the Electronics Corporation of India Ltd. (ECIL), a public sector company, with funding provided by the Department of Electronics. ECIL had already been started at Hyderabad in 1967 by the Government of India and was under the administrative control of the Department of Atomic Energy. It was originally established to commercialize electronic systems developed at the Atomic Research Centre at Mumbai.

4.1 THE POLITICAL ENVRONMENT

The Congress party, which spearheaded the independence movement, governed India uninterrupted from 1947 to 1977. The public sector had a pre-eminent role in the economy. All major banks in the private sector were nationalized in 1969 by the then Prime Minister Mrs. Indira Gandhi. Thus capital was controlled by the government. All industries were centrally controlled. India had a perpetual balance of trade deficit. The rupee was not convertible. Thus obtaining foreign exchange for import of equipment required elaborate justification.

There was also some trepidation regarding the impact of computers on employment. The Ministry of Labour, Employment and Rehabilitation had set up a committee in 1969 under the chairmanship of R.Venkataraman (then a member of the Planning Commission) to examine the impact of automation on employment. The committee was later chaired by V.M.Dandekar and came to be known as the "Dandekar Committee on automation". This committee prescribed in 1972 strict controls on introducing computers in industry and government departments [36]. The committee also made it mandatory to get prior agreement with labour before introducing computers in organizations. The report of this committee constrained the introduction of computers in banks, insurance companies and many private companies. One of the reasons for the

negative attitude of Dandekar committee towards computerization was the dominance of IBM 1401s which were small machines primarily used for payroll processing, accounting and stores control. White collar workers who were quite vociferous saw these computers primarily as labour saving devices and not as machines which can be used to improve productivity of plants and processes. Even though unit record equipment consisting of card punches, sorters, and accounting machines were already in use, they required a number of human operators and were slower and thus not considered as a threat to employment. The Public Accounts Committee of the parliament in its report of 1975 was also very cautious [37]. The committee opined that even though it is argued that the use of computers lead to efficiency which in turn leads to profit and faster economic growth, it is only true in the long run. The committee felt that in India with large scale unemployment, the use of computers and other sophisticated machines for labour saving applications may not be desirable or may even be detrimental. It recommended that the government should take into account the social cost of computerization and evolve a principled and positive approach on computerization keeping in view the overall national interest.

The Department of Electronics was constrained by these observations and had to move cautiously. In 1970 the responsibility of giving import licences for computers was transferred to it as a "single window clearance". The department drafted an elaborate set of rules [38] for import of computers based on essentiality, whether equivalent computers were made in India and how much foreign exchange was required. Quadrupling of oil prices in 1973 by the Organization of Petroleum Exporting Countries (OPEC) accentuated the problem of foreign exchange, as India imported most of its oil required from the Middle East. In most cases (unless the cost of the computer was being paid for by the UNDP or a foreign government) there was a long delay of one to three years in obtaining clearance to import computers. In a fast changing field such as computers this delay was unacceptable. This delay and restriction particularly hurt companies which wanted to import computers for software export. It also adversely affected the projects of many industries, scientific research laboratories and universities.

The other major political event which affected the development of computers was the war with Pakistan in 1971 which ended with the creation of Bangladesh. Richard Nixon, the US President, favoured Pakistan and it resulted in embargos on electronics and computer imports from the USA. The first nuclear test by India in 1974 further aggravated Indo-US relations leading to an embargo on the import of electronic equipment using advanced technology which included high-end computers and sophisticated software used in science and engineering.

4.2 GOVERNMENT POLICY

With the establishment of the Department of Electronics (DoE) and the Electronics Commission (EC) in 1970 the responsibility of formulating policies on electronics including computers was delegated to them. M.G.K.Menon was appointed the secretary of the DoE and ex-officio chairman of the EC. Menon was the Director of TIFR when he took over the DoE. He depended heavily on the report on computer development submitted by R.Narasimhan which was a part of the Bhabha Committee's report of 1968 [39]. This committee recommended that computers, other than the larger ones, must be locally manufactured. It opined that "attaining self-sufficiency in systems engineering and fabrication is of fundamental importance from the point of view of the defence and security of our country". It also felt that from a long range perspective India should upgrade its capability to design and manufacture smaller computers. Consequently ECIL was fully supported in its manufacturing programme with funding from the DoE. However ECIL was not very successful in selling data processing systems to private companies. In the meanwhile computer technology was rapidly progressing in the west and with the development of Large Scale Integrated Circuits (LSIs) price of computers was falling. There was a demand from many private companies to allow them to manufacture computers as they were already manufacturing electronic calculators. The DoE was expected to announce a "minicomputer policy" which would formulate the ground rules for the private players to manufacture computers. Still the DoE kept on delaying the announcement of a minicomputer policy as it was concerned about the requirement of foreign exchange as many components and peripherals had to be imported. The DoE was also protecting ECILs programme which it had funded. A panel on minicomputers chaired by P.V.S.Rao appointed by the DoE [40] opined that mini computers can be made in India without any foreign collaboration or importing know-how in hardware or in software. The panel also suggested standardization to reduce the variety of components which would be imported. They argued that standardization would allow bulk purchase and reduce capital cost besides reducing maintenance cost. However the emphasis on standardization was not agreed upon as private companies wanted leverage in order to differentiate their products.

Meanwhile in the general elections held in 1977 Indira Gandhi was defeated and a coalition government with Morarji Desai of the Janata Party as the Prime Minister assumed charge. Menon, the secretary of the DoE, was replaced. A minicomputer policy was ultimately announced in 1978 which was more or less along the recommendations of the minicomputer panel. Also 1978 was the year IBM left India and the policy announcement was timely as a number of private entrepreneurs were ready to occupy the space left by IBM.

4.3 GOVERNMENT INITIATIVES

4.3.1 ECIL's Computer Division

We saw in the last section that the DoE decided to support self-reliant indigenous production of small computers by funding ECIL's computer division [41]. S.Srikantan who was chosen to head this division, had designed the mini-computer Trombay Digital Computer – 12 (TDC 12) while he was working at the Atomic Research Centre at Trombay. It was a 12 bit real-time computer whose architecture was similar to the then popular PDP-8 computer made by the Digital Equipment Corporation in the USA. It was not identical to PDP-8 as it had some extra instructions. System software had to be developed *ab initio* for this machine. The effort required was underestimated by the ECIL engineers.

ECIL did not have a commercial computer on which software could be developed. Software work was outsourced to TIFR, IIT/Kanpur, and IIM/Ahmedabad besides local efforts at the ECIL. An Operating System, an assembler, BASIC, and FORTRAN compilers were developed. In the meanwhile technology was changing. The TDC 12 was upgraded in 1974 to a TDC 312 which used transistors. This was followed by a TDC 316, a 16 bit computer built in 1975 which also had ECOBOL, a version of COBOL compiler. When microprocessors became available ECIL manufactured a microprocessor based system MICRO 78 in 1978. The numbers of computers sold by ECIL during 1971 to 1978 were 21 TDC 12s, 32 TDC 312s, 35 TDC 316s and 10 Micro 78s, totaling 98 machines [42]. The specifications of TDC series machines are given in Table 1 [43]. Besides this, 75 ruggedized TDC 316 computers were deployed in a defence project which we will describe later in this section.

Table 1. Specification of ECIL Machines

Machine	Word length (bits)	Memory size (words)	Cycle time (μsec)	Technology	Software	Typical cost (Rs.)
TDC-12	12	4K to 32K	2	Vacuum Tubes	Assembler Fortran II	600,000
TDC-312	12	4K to 32K	2	IC	Assembler Fortran II	1,000,000
TDC-316	16	8K to 32K	1	IC	Assembler Fortran IV and COBOL	3,000,000

During the period 1971-78, ECIL demonstrated that computers could be manufactured in India with local components, imported ICs, and peripherals. It however worked more like a cottage industry as the volume of production was

small. ECIL's sales effort was poor and hence it could not sell its machines easily. Most of the ECIL machines were bought by the Atomic Energy Establishments, government departments and Universities which obtained grants from the government and were constrained to buy the ECIL machines. Only 4 machines were sold to the private sector [42]. ECIL machines were overpriced and did not have sufficient software. However, the contribution of the ECIL was in the training of over a thousand engineers in designing systems and developing systems software. Many of them later joined the private manufacturers and software companies to lead groups there.

An important contribution of the ECIL was in providing ruggedized computers for the Air Defence Ground Environment Systems (ADGES) of the Indian Air Force. These systems had to be designed and fabricated with Indian know-how and in institutions located in India due to their sensitive nature. Import would have been difficult as sensitive information had to be revealed to vendors and very often India was subjected to sudden embargos on electronic systems by the USA and its allies. These systems were deployed along India's borders to detect intrusion by non-friendly aircrafts. The system design and the software were developed by TIFR under the leadership of P.V.S.Rao [44]. Each system used three TDC 316 computers. The computers were ruggedized with components adhering to MIL specifications. Each system was connected to 8 display units (co-developed by ECIL and the Tata Electric Company) with fairly complex interface electronics. The systems with radars developed by the Electronics and Radar Development Establishment, Bangalore were designed and deployed during 1969-1984. The cost of each system was Rs.30 million and 25 systems were deployed by the Indian Air Force. The income from this project sustained other developmental efforts of ECIL. In the published literature this important contribution of ECIL is not mentioned. In fact the system could have been modified for use in Air Traffic control systems but ECIL did not pursue this opportunity.

Besides this, ECIL's TDC 312s and 316s were used in many nationally important projects where export controls made it difficult to import computers. Some of them were data acquisition systems for the department of atomic energy, monitoring launching of satellites, telemetry for the department of space, engine testing for gas turbines and launch vehicles of the department of defence. The deployment of TDC 312s in data logging of rolling mills and in controlling the cutting of billets in steel mills with locally designed software could not have been done economically with imported computers. The DoE gave grants/loans of Rs. 37.44 million to ECIL [5, p.30]. A detailed analysis of the investments made by the government and the profit and loss account of ECIL may be found in [45]. A brief history of ECIL may be found in the article by Vijayakar and Mayya [41].

4.3.2. Other Initiatives

The Department of Electronics was set up with the primary objective of promoting the development of electronics and computer industry. However, during the period 1970-77 the general perception was that it was playing more of a regulatory role and protecting the public sector company ECIL it funded. The political environment and the foreign exchange crunch forced the DoE to take certain actions particularly in regulating import of computers. The DoE became very unpopular as a number of legitimate requests for the import of computers by educational institutions, scientific departments of the government and industry were scrutinized and inordinately delayed. To compound this no private Indian company was allowed to manufacture computers.

Regardless of this perception the DoE did play a promotional role in a number of areas. The important initiatives taken by the DoE during this period were:

Establishing NCSDCT. The DoE established the National Centre for Software Development and Computing Techniques (NCSDCT) at TIFR, Mumbai. This centre was set up in 1972 with a grant of Rs.2.85 million from the DoE and USD 2 million from the United Nations Development Programme (UNDP). This centre installed a dual processor DEC 1077 and a PDP 11/40 based vector general interactive graphics computer. A large number of scientists were sent abroad for training. Later it was hived off from TIFR and renamed the National Centre for Software Technology (NCST) in 1983. NCST trained a large number of scientists in advanced software and was instrumental in bringing Internet to India. A core group of scientists who were employed by the NCST later became leaders in the profession. The history of the NCST may be found in the article by S.Ramani [46]. C.R.Subramanian [5, p.231] also describes the activities of NCST critically.

Setting up the National Informatics Centre. In 1975 the DoE set up the National Informatics Centre (NIC) whose main purpose was to assist in e-governance initiatives of the central and state governments. The DoE invested Rs.31.72 million and the UNDP provided funding of USD 4.4 million. A large computer centre was set up in New Delhi for data processing of the central government. NIC pioneered later by creating a VSAT network connecting computers spread all over India. Besides this it collected statistical data for the Planning Commission of the Government of India and started e-governance projects in many states. Details of NIC's history may be found in the article by N. Seshagiri [47].

Funding Army Radio Engineering Network (AREN). The DoE initiated the creation of AREN which included mobile communication links from forward areas via several automatic electronic switches up to the Army Head Quarters. This was a multi institutional project involving the TIFR, the Electronics and Radar Development Establishment (A Defence Laboratory) and the Army's signal engineers. The electronic automatic call routing switch developed by this project under the leadership of M.V.Pitke was later modified and used for rural

electronic telephone exchange switch which ushered in the communication revolution in India [44].

Promoting Software Export. Recognizing the potential of software export DoE allowed import of computers exclusively meant for software export. The first policy paper on this was published in 1974 [48]. One of the companies which used this opportunity effectively was the Tata Consultancy Services under the leadership of F.C.Kohli. TCS imported a Burroughs B6700 computer and developed software for it. TCS converted software running on computers of other manufacturers to run on the Burroughs computer. Many such jobs were outsourced by Burroughs to TCS. TCS was also an early pioneer which actively scouted for programming work from outside India in Iran, Switzerland, South Africa, and Canada besides the USA. TCS was able to demonstrate that software services export from India was feasible and profitable. Tata and Burroughs formed a company to manufacture computers in Mumbai in 1975. The company was not successful and was closed down after four years. S.Ramadorai, who succeeded F.C.Kohli as the CEO of TCS in 1996, has written the history of TCS [115].

Funding the establishment of Regional Computer Centres (RCCs) with main frames. The DoE set up RCCs in University campuses to promote the use of computers by industries and educational institutions in the region. For example, the RCC at Jadavpur University started in 1977 and had a Burroughs 6738 main frame and allowed free access to it to students in the eastern region of India [49,110]. Regional Computer Centres were also set up in Pune and Chandigarh.

Establishing the Computer Maintenance Corporation (CMC). Foreseeing the departure of IBM from India, the DoE established CMC in 1976 to maintain imported computers and to maintain the computers left behind by IBM. CMC was setup at a cost of Rs.53 million [5, p.30]. CMC went on to be a very important company which took up many nationally important projects [50].

Funding Air Defence Ground Environment System Development (ADGES). Recognizing the importance of designing an air defence system for India the DoE funded the ADGES project at the TIFR. This important project was described in greater detail earlier in this report.

On the negative side, during 1970-77 the DoE delayed the entry of the private sector into computer development. No concerted effort was made to develop a semiconductor industry which was an urgent requirement. Even though Menon understood the importance of manufacturing semiconductor devices and set up a committee in 1971 whose report was submitted in 1973 no tangible action was taken till 1978. Even then the investment was sub critical. While the rest of the world was surging ahead in manufacturing integrated circuits India was left way behind [51].

5. PRIVATE SECTOR ENTERS THE COMPUTER INDUSTRY (1978-1990)

This period saw the beginning of liberalization and the entry of private enterprise in computing. Even though the political environment was choppy during this period, Rajiv Gandhi who belonged to the post-independence generation and was open minded regarding private enterprise ushered in significant changes when he became the Prime Minister. The major events during this period were the exit of IBM, the entry of private manufacturers of computers who made UNIX based minicomputers, the beginning of software export through "body shopping" (i.e., sending software engineers to client sites abroad to develop software), and the advent of off-shore software development using satellite communications first by Texas Instruments and later by Indian software services companies from Software Technology Parks (STPs) set up by the DoE which provided satellite communication facilities to these companies to communicate with their off-shore clients. The number of computers in India which was less than 1000 in 1978 increased to 80,000 in 1990. There was insignificant software export in 1978 whereas it increased to USD128 million in 1990. In this section we will describe how some significant changes in government policies led to these important changes which later resulted in the software industry taking off and growing exponentially.

In 1973 India had enacted the Foreign Exchange Regulation Act (FERA) to conserve foreign exchange. Under this act foreign companies except those considered essential were to dilute equity to 40% and take an Indian partner. IBM was requested to fall in line but refused as it was not its global policy. In the meanwhile IBM gave a proposal to the government to set up a 100% export oriented manufacturing unit in India and use the export earnings to import computers for sale in India. IBM also proposed that 26% of its profit would be invested in an R and D Centre to be set up in India. With this counter offer IBM was very confident that it would be considered "essential" and the FERA would be relaxed in its case. IBM's confidence arose from the fact that there were over 150 IBM installations in India. Indian Railways, the Planning Commission, many textiles and petrochemical companies, and numerous educational and research laboratories had installed IBM computers. IBM's data centres were widely used and its service was excellent. After prolonged negotiations the government was unwilling to relax FERA for IBM. Consequently IBM decided to withdraw from India in 1978. A detailed discussion of IBM's negotiations with the Government of India may be found in the book by C.R.Subramanian [5, pp.161-176]. IBM's business in India consisted of refurbishing used IBM 1401s and renting them, maintaining IBM computers, manufacture of cards, and running data centres. When IBM left India in 1978 the refurbishing operations stopped. The computers which were rented were sold to the customers at their book value which was almost zero. The card manufacture and data centre operations were taken over by a group of ex-IBM employees who formed a company called International

Data Machines (IDM). Maintenance of IBM computers was taken over by the Computer Maintenance Corporation (CMC) which had been set up by the DoE in 1976 to maintain imported computers foreseeing such a contingency. All spare parts of IBM 1401s and other computers were sold to CMC at nominal price. Most employees of IBM joined CMC. There was thus no disruption of operations of computers [4].

ICL, the British Company, diluted its equity as per FERA and formed the International Computer India Manufacturing Ltd. (ICIM) in collaboration with a local partner. In 1977 ICIM started manufacturing a computer series called ICL 2900 [52].

5.1 THE POLITICAL ENVIRONMENT

The period 1978 to 1990 was a period of political instability in India. In the general election held in 1977 the Congress party which had continuously governed India from 1947 to 1977 was defeated. A coalition government led by Morarji Desai took over. Menon was moved away from the DoE to the Department of Science and Technology in 1978 and Biswajit Nag became the new secretary of the DoE and the chairman of the EC. The coalition government did not last its full term and fell in 1980. In the general election that followed Indira Gandhi returned as the Prime Minister in 1981. B.Nag resigned in 1981 and was replaced by P.P.Gupta as the secretary of the DoE. In 1984 Indira Gandhi was assassinated and her son Rajiv Gandhi took over as the Prime Minister. He won the next general election and was the Prime Minister from 1984 to 1989. In the general election of 1989 the Congress party lost and a coalition with V.P.Singh as the Prime Minister assumed power. This coalition was unstable and fell in 1990. In the next general election in 1991 the Congress party returned to power. The new government faced a very difficult economic situation. India was about to default and unable to pay its external debts. It was bailed out by the International Monetary Fund and the World Bank which imposed a set of conditions that forced India to liberalize its economy. The liberalization changed the course of history of computing in India which we will discuss in section 6.

5.2 GOVERNMENT POLICY

In spite of the political instability as outlined, computing progressed at a much faster rate during 1978-1990 compared to the period 1970-1978. The period started with the appointment of a committee with Mantosh Sondhi as its chairman and B.Nag as its secretary [53]. The committee's task was to review the progress of electronics and computing. The committee observed that there have been long delays in importing computers due to the cumbersome procedures of the DoE. It suggested simplification. The Sondhi committee also suggested liberalization of the manufacture of computers by private manufacturers. It opined that the major emphasis in the development of the

minicomputer/microprocessor industry would be on setting up of systems engineering companies which were not necessarily engaged in the manufacture of central processing units or peripherals. It added that small scale entrepreneurs should be preferred for manufacturing special purpose computers for dedicated applications such as data entry, data acquisition, accounting and invoicing, typesetting, and dedicated controllers. The policy also stated that it would continue to be restrictive in allowing use of computers in areas where labour displacement was likely to be involved. Foreign technical/financial collaboration was in general not permitted. In special cases foreign equity participation up to 40% was allowed in minicomputer manufacturing. As was the norm during that period, all entrepreneurs had to apply to the government giving detailed plans of manufacture to obtain a licence. There were various constraints such as total production value should not exceed Rs.20 million and a limit on the number of computers to be manufactured. Only the public sector company ECIL would be allowed to manufacture 32 bit computers.

Two other events had a far reaching impact on the government policy. Asian Games were to be held in Delhi in 1982 and Rajiv Gandhi, the son of the Prime Minister Indira Gandhi, was asked to assume overall responsibility of organizing the games. He was technically savvy, being an amateur electronics buff. He decided that computers should be used to draw up the games' schedules, event records, announcement of results, and all other clerical chores. Locally made DCM computers were used as terminals at various venues and connected to a Hewlett Packard server. The entire software system was developed in a short period of six months by the software engineers of the National Informatics Centre (NIC) of the Government of India. The computerization of the games was a resounding success. This brought N.Seshagiri, the Director General of the NIC, close to Rajiv Gandhi [54].

In 1984, Indira Gandhi was assassinated and Rajiv Gandhi became the Prime Minister. He had heard from the private entrepreneurs during his interactions with them when he was organizing the Asian Games their difficulties in manufacturing computers due to myriad rules and regulations. N.Seshagiri who was his informal advisor was also aware of the difficulties faced by the private entrepreneurs in manufacturing and marketing computers. The time was thus ripe for further liberalization of policies relating to the manufacture of computers. A liberalized policy on minicomputers was announced in 1984 with the following main highlights [55]:

- Any manufacturer could manufacture 32 bit machines.
- All capacity constraints (namely, the number of computers that could be manufactured) were removed.

- Assembled boards with microprocessors and boards with interface electronics could be imported. This policy had a subtle effect. It changed manufacturing to assembly and system integration. In other words fully populated boards could be imported which were more reliable and cheaper than boards fabricated using locally manufactured components and imported microprocessors. Import duty was also reduced on "ready made" boards. Thus local manufacturing of boards slowly disappeared.
- Import of application software was allowed and duty reduced.
- Import of mainframes for legitimate use was allowed and the procedures were simplified.

The policies to protect public sector companies, ECIL and CMC, were continued by:

- Reserving manufacture of superminicomputers and mainframes for ECIL.
- Compulsory maintenance of imported computers by CMC or by the users themselves and not by the manufacturer.

Policies for promoting software exports were liberalized by:

- Recognizing software development and services as an "industry". This recognition led to many concessions such as getting loans from banks and duty exemptions. Software was exempted from excise duty.
- Customs duty on imported computers for software export was reduced. Earlier it used to be over 100%.
- Sending engineers abroad to develop and maintain software for clients at their sites and profits earned thereby was recognized as "software export".

In 1986 there were further incentives for software export [56]:

- Computers used to develop software for export could be imported duty free. However, the importer was expected to export software and earn 250% of the cost of the imported computer within 4 years.
- If no foreign exchange was spent to import a computer (e.g., a non resident Indian bringing a computer with his earnings) then the export obligation was 150% of the cost of the computer.
- Software tools needed to develop software for export could be imported duty free.
- Software developed in India could be exported using communication systems such as satellite and cable.

- CMC had set up a network of IBM 4342 mainframes known as Indonet [10]. This network was allowed to be used by software exporters at a concessional tariff.

Besides these policy changes there were also reforms in the area of communications. The public switched networks as well as overseas communication links were the monopoly of the government and were run by a government department with its employees having the status of government servants. As a government department its budget was part of government budgeting resulting in low investment and poor service. In 1982 there was a waiting time of over 2 years to get a land line telephone connection. While the rest of the world was surging ahead in providing inexpensive communication facilities, the infrastructure in India was primitive. Under the leadership of Rajiv Gandhi two policy decisions were taken. The first one was to corporatize the public switched telephone network. A public sector company called the Mahanagar Telephone Nigam Ltd. (MTNL) was formed to operate telephone services in Mumbai and Delhi. It was given operational autonomy. Another company named the Videsh Sanchar Nigam Ltd. (VSNL) was established in 1986 to improve overseas communication. In 1984 a research group was formed under the leadership of Satyanarayan (Sam) Pitroda assisted by M.V. Pitke (who had led the AREN group discussed earlier) and G.B.Meemamsi (an officer of the Department of Telecommunication). It was called the Centre for Development of Telematics (CDOT) [57]. The main goal of CDOT was to design digital exchanges of small capacity suitable for use in rural India which had problems of poor power availability and extreme weather conditions (45^{o}C in summer and -5^{o}C in winter). CDOT recruited a highly motivated group of engineers and developed a rugged switch and a digital exchange in a record time of 3 years. CDOT switches were widely deployed and they performed very well.

Another important revolution in rural telecommunication in India was the development of public telephone booths with microprocessor based systems for billing telephone calls. These were called Public Call Offices (PCOs). The public could place local, long distance, and international telephone calls from these PCOs and pay the charges to an attendant. A microprocessor attached to the telephone printed the cost of a call as soon as it was completed which enabled transparent toll collection. The cost of establishing such PCOs was low which enabled a large number of entrepreneurs to enter this business. These privately owned PCOs became ubiquitous in small towns, villages, and on highways all over India leading to a communication revolution. Every nook and corner of India was connected within 5 years. The power of microcomputer was visible to all [58].

5.3 GOVERNMENT INITIATIVES

We saw that during 1970-78 the Department of Electronics had taken a number of initiatives which had a long range impact on the development of computing in India. The period 1978-90 was also marked by a number of initiatives taken not only by the DoE but also by other organizations which accelerated the use of computers. We describe below some of the important initiatives.

Spreading computer education in IITs. IIT/Kanpur which had started the first Master's Programme in Computer Science in India again pioneered in starting an undergraduate programme in Computer Science in 1978. It was the first IIT to start such a programmme and did so under my leadership. Entry to IITs is highly competitive and over 100,000 students took the entrance examination from all over India for the 1500 seats (in 1978) and students were given the choice of the IIT and the programme they opt to join based on their rank in this examination. The IIT/Kanpur senate had grudgingly allowed 20 students to be admitted to the Computer Science (CSc) programme as it felt that CSc was not "mainstream" engineering. However, the CSc programme was so popular among the students that the rank of the last student admitted to the IITK CSc course was 40! This came as a surprise to other IITs and all of them started B.Tech programmes in CSc [26]. Soon a Department of Computer Science and Engineering was started in all the IITs offering B.Tech, M.Tech and Phd degrees in Computer Science and Engineering.

Human Resource development in IT. In 1980 the Electronics Commission foresaw the problem of scarcity of human resources for the emerging computer industry. A Panel on Computer Manpower Development under my chairmanship (I was also a member of the Electronics Commission during 1979-1982) was formed to suggest solutions. The panel recommended expanding the undergraduate programmes in Computer Science at IITs and other engineering colleges [59]. Another novel proposal of the panel was to start a new programme called Master of Computer Applications (MCA). In the Indian education system, after graduation from high school, a large number of students enroll in a three year B.Sc course with physics, chemistry and mathematics as the main subjects or in B.Com course with commerce, economics, and statistics as the main subjects. These degrees are general ones and do not prepare a student for a profession which requires specific skills. It was felt by the panel that India needed a large number of persons to develop business/management information systems for use in organizations both in India and abroad. This required systems analysts with some breadth in education and specialization in software development. The curriculum was planned to encompass three disciplines: computer science with emphasis in software engineering and systems analysis, mathematics to be able to develop systems which require operations research and application of statistics, and management science for the students to appreciate the nuances of business so that they can design systems understanding the language of managers. The programme design included a semester of actual system design in an organization. While B.Tech and M.Tech CSc students were expected to design

computer systems (hardware and software), MCAs were expected to design software systems for management and business applications. This programme which was uniquely Indian provided an opportunity to a large number of B.Sc/B.Com students to become professional information system designers. Initially the Government of India decided to fully fund ten institutions to start this programme. The availability of well trained MCAs was one of the contributing factors for the rapid growth of software services industry in India. Details of the MCA programme may be found in [60, 61].

Promoting software export. In 1981 the Electronic Commission appointed a committee with me as its chairman to promote software export by allowing import of computers. The committee recommended liberalization of import of computers for genuine exporters [62].

Assisting neighbouring countries in computerization. CMC obtained funding from the UNDP of USD2.75 million for a programme called the International Education and Research for Application of Computer Technology (Project INTERACT). It spread the use of computer technology to neighbouring developing countries by designing training programmes in software development and computer maintenance [5, p.271].

Programme in Computer Aided Design (CAD). DOE obtained a grant from the UNDP of USD 1.5 million in 1984 and contributed Rs.340 million to establish CAD centres at IIT/Kanpur, IIT/Bombay, Indian Institute of Science, Bangalore and Jadavpur University [5, p.259]. These centres developed software and human resources in various areas of CAD. The centre at the IISc/Bangalore, of which I was the coordinator, specialized in developing CAD tools in electronics. The IISc CAD centre collaborated with the Delft University of the Netherlands and obtained NELSIS, a tool for large scale integrated circuit design. Many scientists went abroad to get trained in the design and use of CAD tools and later on developed tools of their own and assisted the industry by offering short term courses and providing trained human resource. (During the mid 80s the US Government had banned the export of CAD tools in electronics to even educational institutions in India.)

Computer Assisted Management Programmes. In 1984 the DoE along with the UNDP funded a programme called Computer Aided Management in the three Indian Institutes of Management at Ahmedabad, Bangalore and Kolkata and at the Administrative Staff College of India, Hyderabad. This project had two aims. One was to initiate research in the application of computers in management to improve the efficiency of organizations. The other was to train students at these institutes and practicing managers to use computers to improve the functioning of organizations. A total grant of USD 1.25 million and Rs.35 million was provided. Each institute also got a VAX II/750 computer and a number of software packages in optimization. The project was very useful in educating managers in systems analysis and using appropriate software to improve management processes [63].

Promoting offshore software development. The DoE negotiated with the Department of Telecommunication (DoT) in 1985 to allow Texas Instruments (TI) to set up a dedicated satellite communication link to its centre at Dallas, USA. TI's centre in Bangalore developed software tools and sent them to its Dallas centre via a dedicated satellite communication link. This was the first step in breaking the monopoly of the DoT in communications and had far reaching consequences later in the growth of "off shore" software development centres and the Software Technology Parks programme of the DoE [64].

Teacher Training Programme. The DoE set up a committee in 1985 with S.Sampath as its chairman which suggested training teachers in Computer Science for the colleges which were being newly established [65].

Knowledge Based Computer Systems Development Programme. The DoE obtained funding in 1985 from the UNDP of USD 5.2 million and invested Rs.140 million to start a programme called the Knowledge Based Computer Systems (KBCS) development. The participating institutions were IISc, Bangalore, IIT/Madras, ISI/Calcutta, TIFR/Mumbai and NCST/Mumbai. This programme led to the design of parallel computers, expert systems in medicine, soft computing including script recognition of Indian languages and research in speech recognition and knowledge representation. A large number of scientists from these institutions were sent abroad for working in renowned Universities in the USA and in the UK. This programme also improved the research infrastructure available in the participating institutions [5, p.261].

Promoting use of computers in banks. A committee set up by the Reserve Bank of India (RBI) with R.Rangarajan as its chairman recommended that all banks should have EDP cells and all back-office work was to be done using computers. The committee also recommended the use of UNIX as the standard Operating System (OS) in banks .The computer requirements of banks were large and gave an impetus to private computer manufacturing companies to design and develop minicomputers using UNIX as the OS. The increase in computer use by banks was a red flag to the trade unions and they observed 1984 as "anti-computerization year" [66]. This perception changed in 1986 when a passenger reservation system was implemented by CMC for the Indian Railways.

Establishment of a National Supercomputer Education and Research Centre. The Ministry of Human Resources Development of the Government of India gave a grant of Rs.500 million (Rs.12 per USD) to the Indian Institute of Science, Bangalore in 1984 to set up a Supercomputer Education and Research Centre (SERC). A national committee was constituted to select appropriate computers for the SERC. The committee visited two companies in the USA and one in Japan and suggested a Cray YMP as the main supercomputer, a number of front-end computers and numerous high end workstations. An order was placed with Cray and the company signed a contract to install the Cray YMP at the Indian Institute of Science by 1989. Cray was confident of getting a licence to export the computer to the Institute. A team led by an official of the US Department of State visited the institute and a number of conditions for the use of the

computer were negotiated and mutually agreed. As the chairman of SERC of the Indian Institute of Science between 1982 and 1994, I participated in the entire exercise. The US government did not give an export licence to Cray before the date specified in the contract signed by the IISc with Cray. The committee decided to cancel the order given to Cray and buy instead a Cyber992 mainframe with a vectorizer, the fastest mainframe made by CDC at that time, along with two CDC 4360 superscalar computers and a VAX 8810 from DEC. The Institute also decided to take a cluster computing approach by buying 9 IBM RS6000/580 superscalar workstations (without displays) each with 256MB memory interconnected by a dual Fibre optic communication ring. Besides these, 48 IBM RS6000/340 workstations in a network provided remote access to the systems. In addition 24 Silicon Graphics workstations were bought to aid visualization, modelling and simulation. The IISc also bought in 1992 a PARAM 8600 parallel computer (made in India by the Centre for Development of Advanced Computing to be described in what follows) which had 64 scalar and 16 vector processors. In 1992, SERC at the IISc was the largest computer centre in India with a large number of computers and a huge library of packaged software. The entire campus was networked with fibre optics. The denial of Cray was a blessing in disguise as the money saved was used to buy state-of-the-art powerful parallel computers. The Supercomputer Education and Research Centre continued to receive support from the Government of India and by 2010 it had an IBM Blue Gene supercomputer, three high performance computer clusters and an improved campus network. (By 2010 the US government had loosened export controls on supercomputers to India [116].)

Establishment of the Centre for Development of Advanced Computing. The Science Advisory Committee to the Prime Minister chaired by C.N.R.Rao set up a committee in 1986 with me as its chairman to suggest methods of designing and fabricating high performance computers. The committee was formed as a consequence of the difficulties encountered by India in buying supercomputers from the USA and Japan. The committee suggested a mission mode project to build parallel computers with a speed of a giga-flop or above. Consequently, the DoE established a Centre for Development of Advanced Computing (CDAC) at Pune in 1988 with an initial investment of Rs.300 million to build high performance parallel computers. The project was successfully completed in 1991. CDAC went on to build more powerful parallel computers and in 2007 built a machine called PARAM PADMA which was ranked 171 in the list of 500 fastest computers in the world [67]. Besides its efforts in parallel computing, another notable contribution of CDAC was the development of an integrated circuit chip called GIST (Graphics and Intelligence based Script Technology) which could be mounted on an add-on board for a PC [5, p.129]. This board facilitated the use of most Indian language scripts with PCs. GIST used a standard Indian Script Code for Information Interchange (ISCII). A common keyboard layout for different Indian scripts was also designed.

Parallel Computer Design Projects. Besides the effort by CDAC there was a flurry of activities in designing parallel computers between 1985 and 1992. A number of other institutions also designed parallel computers as research projects and

for their internal use. Notable among these were FLOSOLVER, a machine to solve fluid dynamics problems by the National Aeronautical Laboratories at Bangalore, PACE by the Defence Research and Development Organization at Hyderabad, and ANUPAM by the Bhabha Atomic Research Centre at Mumbai. As part of the KBCS project several low cost parallel computers using PC motherboards were built at the IISc at Bangalore. Around ten students at the IISc obtained doctorates working on various aspects of parallel computing. All the projects described above generated a large pool of engineers adept in designing and programming parallel computers.

Computerizing the ticket reservation system of the Indian Railways. A major project to computerize the reservation of tickets in the Indian Railways began in 1984 and was completed in 1986. India has one of the largest railway networks in the world. In 1984 it handled over 5 million passengers travelling in over 600 long distance trains with around 50,000 reservation requests. Passengers had to stand in long queues to obtain reservations. Clerks kept numerous ledgers, one for each train, and they had to juggle between ledgers depending on the choice of trains by the passengers. The area of reservation was ripe for computerization. CMC gave a proposal to the railways to computerize the reservation system. This was accepted by the railways and by 1986 a reservation system was developed and implemented at the New Delhi booking office. It had 50 counters and customers could go to any counter to get a reservation done for any train [68]. Reservation on connecting trains as well as return reservations could also be done. Cancellation of tickets and getting an immediate refund was simplified. This was perceived in 1986 by the general public as almost a miracle. Instead of waiting for hours to get a reservation and having to run from counter to counter the customers could get confirmed reservations within 30 minutes as there were 50 counters. The counter clerks were also happy as they could reconcile the collected cash against issued tickets with the help of the computer within 30 minutes after closing time whereas in the manual system it used to take at least two hours. There was also no reduction of staff; in fact there was an increase as more counters were operated with more clerks working simultaneously. The system interestingly was developed on a VAX cluster connected to terminals at the counters. FORTRAN was used as the programming language [68]. It was the first time in the world that such a system was developed for on-line transaction processing on a VAX cluster. The entire software effort was by Indian software engineers with no involvement of "foreign consultants. The reservation system using computers was an eye opener to the general public as it demonstrated the advantages of using computers. There was an attitudinal change among both the general public and the white collar workers about computerization. This was the beginning of the acceptance of computers and the realization that in a country which has large volumes of data to be processed the use of computers is inevitable. Some bank unions also accepted computerization, suggested by the Reserve Bank of India, which they had opposed earlier.

Initiatives in computer networking. In 1986 the DoE obtained a funding of USD 6 million spread over 4 years from the UNDP with Government of India funding of

Rs.41 million for a project titled Education and Research in Computer Networks (ERNET). This project had the involvement of all the five IITs at that time, namely, IIT/Bombay, Delhi, Kanpur, Kharagpur and Madras, IISc/Bangalore, NCST, Mumbai and the DoE's technical group as participants [70]. The project was steered by S.Ramakrishnan of the DoE. The primary aim was to link all these institutions for exchange of email and other documents. Besides this the project was to train human resource in computer networking and initiate research work in this area. The project was expected to connect Indian institutions to the Internet. This project was instrumental in creating a significant human resources well versed in computer networking. ERNET also brought the Internet to India under the leadership of S.Ramani of NCST, Mumbai. A review of this project by the UNDP commended the work done and opined that the project goals were met [71]. After the project ended, ERNET became an Internet Service Provider (ISP) to educational and research institutions in India.

Establishing Software Technology Parks of India (STPI). Another major initiative taken by the DoE was the setting up of Software Technology Parks (STPs). Software Technology Parks provided infrastructure such as buildings, work stations and continuous uninterrupted power supply to software companies located in these parks. In addition STPs established satellite communication links which could be used by these companies to develop software on the computers of their overseas customers from access terminals located in their respective premises in STP. As the investment required to set up a company in STP was low, this initiative allowed many small entrepreneurs to enter the software services export business. The first STP was established in Bangalore in 1990. STPs were set up later in many other cities and incorporated as STPI [72] controlled by the DoE.

Development and use of Electronic Voting Machines. Another significant event which took place in 1982 was the use of microprocessor based electronic voting machines (for the first time probably in the world) in a bye election to the Indian Parliament held in Kerala [69]. The electronic voting machine (EVM) was designed by two public sector companies: the Bharat Electronics Ltd., and the ECIL, for easy use by the illiterate electorate. The use of EVMs allowed the declaration of election results within two days after voting. (Since the general elections of 2004 only EVMs are used in India. The use of manually filled ballot papers has been discontinued.)

The effectiveness of computers in three highly visible projects, namely, the reservation of train tickets, Public Call Offices, and computerized electronic voting, changed the perception of policy makers and the general public about computers and their relevance to India.

5.4 CONSEQUENCES OF GOVERNMENT POLICY

The minicomputer policy of 1978 opened up the computer industry and saw the emergence of a number of technical entrepreneurs. Even though this policy did

not completely free the industry from the "licence-permit raj" it allowed the entry of private companies to this hitherto reserved green field area of computers. A large number of licences were granted but many who were traders opted out. The ones who started manufacturing were DCM Data Products, Delhi, ORG Systems, Baroda, Hindustan Computers Ltd., Delhi, PSI Data Systems, Bangalore, Wipro Systems, Bangalore, Patni Computers, Pune, IDM, Mumbai and Zenith Computers, Mumbai. They designed their systems from scratch using imported microprocessors, support chips, peripherals, and local components. These companies designed and fabricated printed circuit boards, mounted and soldered all the components and tested the systems.

As software could not be imported they had to develop operating systems, device drivers, compilers and application programs. UNIX was the operating system of choice as it was easily available [73]. UNIX which was developed by Thompson and Ritchie at AT&T in 1969 was unique as it was written in C, a high level language [74]. AT&T was not allowed to market UNIX by the US regulators with the result that it was almost "open source" with several versions being available among which the one developed by the University of California, Berkeley, was very popular. This version was modified and adopted by Indian minicomputer manufacturers. UNIX became the operating system of choice as Rangarajan Committee on bank computerization [66] had standardized UNIX as the OS to be used by the computers to be installed in banks. This market was large and could not be ignored. Thus during 1978-1984 a large number of systems programmers in India became experts in UNIX development and usage. They also adopted C widely as UNIX was written in C. This expertise came in handy when India entered the software services export market in the late 80s.

From 1978 to 1984 there was considerable local design and development of computer hardware systems and application software by private entrepreneurs. A number of original hardware designs and innovations took place. These companies designed mother boards and device drivers, modified the UNIX OS and wrote compilers from scratch. Due to competition the prices came down. ECIL found it difficult to compete with these companies and lost many of their designers to the private sector companies.

The liberalization of 1984 had a deeper impact. Within 2 years of the announcement of the new policy the growth of computers went up by 100% and the cost went down by 50% [5]. The growth was due to the liberal import of fully assembled sub-systems (i.e., populated boards). Manufacturers had to only do systems engineering and develop appropriate software. The old-guard derisively called such manufacturing "screw driver" manufacturing [5, pp.66,73]. However the availability of locally manufactured computers from many vendors allowed consumers choice and competition drove down prices. Allowing import of software tools in 1986 gave an added impetus to software services export [75].

Recognition of software companies as “industry” allowed them to avail of many incentives and obtain bank loans.

Another consequence of the “liberalization” of 1986 saw the entry of many multi-national companies which collaborated with the local companies as minority partners. Hinditron, an Indian company, forged a collaboration agreement with Digital Equipment Corporation (DEC) to manufacture VAX machines in India, Hindustan Computers Ltd. collaborated with Hewlett Packard, and Processor Systems India collaborated with Honeywell Bull. The liberal import of fully populated boards allowed Sterling Computers an “upstart” firm with no previous manufacturing experience to sell Shiva Personal Computer, an IBM PC clone, for Rs.29,000 (Rs.13 per USD) in 1987 [4]. This made PCs affordable and spread the use of computers. Many educational institutions and small companies which could not afford computers earlier were now able to buy a number of computers. (A friend of mine said he was a consultant to PC manufacturers. I asked him what consultation he was providing. His reply was that his job was to locate companies in Taiwan, Singapore and Hongkong which could provide reliable low cost motherboards, floppy disk drives, monitors, power supplies, connectors and cables, the box to assemble all these and to synchronize supplies to the local “manufacturers” who assembled these, put their labels on them and printed a manual.) The emphasis on “self-reliance” and building computers using locally made components which was the cornerstone of the Bhabha Committee report was truly and completely buried. ECIL, the public sector company, which had a monopoly in computer manufacture between 1970 and 1978, and was a “true believer” in self-reliance, could not compete in this environment. It had to first collaborate with Norsk Data Systems of Norway in 1985 and later in 1988 with CDC, a US mainframe manufacturer, to manufacture a version of CDC 810/830 which was renamed Medha 810/830 for the Indian market [76].

The liberalization of the import of computers and software enunciated in the policy of 1986 gave an impetus to the software export industry. From insignificant export earnings in 1978 it increased to USD 131 million in 1990. Breaking the monopoly of VSNL (the overseas communication company in the public sector) by the DoE, providing satellite communication through VSATs at a much lower cost, and establishing Software Technology Parks allowed many entrepreneurs to enter the software export business. Permitting Texas Instruments (TI) to open an off shore centre in Bangalore for software development and allowing TI to link with its Dallas centre via satellite communication was a trend setter. GE computer services, the Citibank software group, American Express, Cadence and many others set up software development centres in India to take advantage of the lower cost and the high quality of software developers.

The government's initiative in starting the MCA course and increasing the undergraduate programme intake in computer science provided human resources. At the same time private initiatives giving non-formal training in software development and computer use also provided the much needed human resources. Aptech and NIIT Ltd. were pioneers in this area. NIIT was established in 1981 and started a franchising model to spread their courses to smaller towns in India in 1987 [77].

This period also saw the establishment of two industry groups: the Manufacturer's Association for Information Technology (MAIT) in 1982, and the National Association of Software and Services Companies (NASSCOM) in 1988. NASSCOM was fortunate in employing Dewang Mehta as its President in 1991. Mehta was a superb lobbyist for software companies and was able to argue the case of software companies effectively with politicians and policy makers in the DoE. NASSCOM started with 38 members in 1988 and by 1999 it had 464 members. A detailed account of the contributions of NASSCOM to the growth of India's software industry may be found in a recent book by Kiran Karnik [109] who became the President of NASSCOM after the untimely death of Mehta.

The DoE which was considered a scientific department along with the Department of Atomic Energy and the Department of Space had technocrats as its secretaries from 1970 to 1988. A difference of opinion between two technocrats in the DoE in 1989 led to the department being taken over by an Indian Administrative Service (IAS) officer who was non-technical and a generalist bureaucrat. The DoE thus became a "non-scientific department". N.Vittal an IAS officer who took over the DoE in 1990 was dynamic and more business savvy as opposed to the technocrats who had previously headed the DoE. He was instrumental in setting up STPs and obtaining a host of fiscal concessions to the software industry by persuading the bureaucrats of the Ministry of Finance.

By 1990 a good foundation had been laid in advanced technology areas such as CAD/CAM, parallel computer development, computer networking and software engineering through a number of research and development projects funded by the UNDP and the DoE. The denial of advanced technology products by the West did not adversely affect India. Instead it goaded India to be self-reliant in advanced technology. The Departments of Atomic Energy and Space and the Defence Research and Development Organization were all denied advanced technology products but were not seriously affected due to the innovations of their scientists and engineers. The only major failing was not investing enough resources to develop a local integrated circuit manufacturing industry. Indian engineers could design large scale integrated circuits, including combined analog and digital systems for TI and other overseas companies but had no foundry to fabricate them in India.

6. LIBERALIZATION OF THE ECONOMY AND SOFTWARE EXPORT GROWTH (1991-1997)

This period was an exciting period for the information technology industry in India. India started with a near default economic situation in 1991 which forced the government to open the economy and dismantle many of the controls on industry which had come to be known as the "licence-permit raj" [78]. The Rupee was devalued (from Rs.17.5 to Rs.26 per USD) and foreign investments and industries were welcomed. This along with fortuitous circumstances of the need to fix the Y2K bug, the Euro conversion requirement, and a technically savvy influential Indian diaspora in the USA opened up opportunities to Indian software companies. This coupled with the advent of fast satellite communication, the availability of human resources with good knowledge of English, quality consciousness of software companies, and project management expertise allowed the software industry to get remunerative software services contracts from the West, particularly from the USA. The export earning which was around USD 128 million in 1991 increased to USD 1759 million in 1997 [82]. The average annual growth rate of 45% of the software services export during this period was spectacular. The industry also provided employment to 160,000 software engineers [79]. Thus by 1997 there was a lot of optimism about the future of Information Technology in India.

6.1 THE POLITICAL ENVIRONMENT

After a period of political instability during 1989 and 1990, a general election was held in 1991. The election was won by the Congress party. During the election campaign Rajiv Gandhi was assassinated by Sri Lankan terrorists and the mantle of leadership fell on P.V.Narasimha Rao, a senior leader of the Congress party. He assumed charge as the Prime Minister at the time when India faced a serious financial crisis. India was about to default on foreign loans; however it was bailed out by the International Monetary Fund (IMF) which stipulated a number of conditions which included devaluation of the rupee, floating it and opening up India to foreign investors. Manmohan Singh, a professional economist, was inducted as the finance minister by P.V.Narasimha Rao. He took the initiative to dismantle a number of controls on the private industry and allowed them to expand. Restriction on foreign direct investments was loosened. These policies known as the end of the "licence-permit raj" and the introduction of "liberalization" had far reaching consequences to all Indian industries. Economic growth which was hovering around 3.8% from 1950 to 1990 suddenly went up to around 7% within two years of liberalization. A number of policy decisions favourable for the growth of the Information Technology industry in India were taken.

In the general election of 1996, the Congress party was defeated. A coalition was formed which did not last and there was political instability with another coalition coming to power. Fortunately successive governments did not meddle with the policies relating to the IT industry. The administrative service officers in charge at the DoE provided continuity in the policy framework.

6.2 GOVERNMENT POLICY

As we saw earlier, the DoE had set up Software Technology Parks with satellite communications which allowed software companies to develop software for off-shore clients from India. A number of concessions were given to software companies after liberalization. The import duty on computers used for software export was abolished. Export earnings of software companies were made tax free for 10 years. Procedures for multinational companies to set up branches in India were simplified. They could be 100% equity companies. According to N.R.Narayana Murthy [80], a very successful entrepreneur (who had founded INFOSYS a software company in 1981 with six of his colleagues), three other policy changes significantly altered the business environment. They were:

1. Convertibility of rupee to foreign currency was eased. This allowed companies to: (i) open offices abroad, (ii) convert rupees to foreign currency to meet marketing expenses, (iii) send software engineers to clients' sites at short notice, and (iv) hire foreign consultants.
2. An office called the Controller of Capital Issues had earlier made it extremely difficult for companies to raise capital through Initial Public Offers (IPOs). The controller rarely allowed premiums on IPOs. This office was abolished allowing entrepreneurs and investors freedom to set market related prices for share offerings. Many software companies floated IPOs.
3. Duty on import of software tools was abolished.

During this period the government also permitted private software companies to have dedicated satellite links with their overseas customers. The National Telecommunication Policy of 1994 [81] allowed private companies to enter the telecommunication business. This had far reaching consequences later, particularly in the mobile communication area. The devaluation of the rupee enabled Indian software companies to be competitive in selling their services and MNCs to start operating in India at low cost.

6.3 CONSEQUENCES OF GOVERNMENT POLICY CHANGES

With the changes in the government policies there was a sudden spurt in activities of Indian software companies – export earning which was around USD 128 million during 1990-1991 went up to around USD 1.76 billion in 1997-1998 [82], an average growth of 45% each year. Indian software companies invented

what is known as the Global Delivery Model (GDM) and the 24 hour work day [80] for Information Technology industry.

The global delivery model allowed development of software for clients abroad by splitting the development process into two parts. One part which typically took 20 to 30% of the time required face to face interaction with customers and was done at the customers' premises abroad. The second part which was primarily coding and testing that took 70 to 80% of the time was done in India. The Indian software companies set up secure areas in their premises devoted entirely to a particular client where the 70 to 80% of the offshore work was done. There was a secure dedicated satellite communication link with the client.

The 24 hour work day model took advantage of the time-zone difference between the USA and India. The prime shift in India was night time in the USA. Clients' computers were relatively free to be used from India. Any bugs reported by the customers when their shift ended could be fixed during the prime shift in India enabling continuous operations of the clients' software systems. The availability of communication links to the clients' computers enabled the 24 hour work day model.

The 24 hour work day model was also used for tasks such as medical transcription. Doctors' case sheets, diagnoses, laboratory reports, and prescriptions were sent to India at the end of the day in the USA. They were entered in databases by operators in India (during India's day time) and sent back early next morning to the USA. Call centres to answer enquiries of customers and assist in fixing bugs in software also used the 24 hour work day model. Such services were called IT enabled Services (ITeS).

The salary of software engineers in India was about 20% that of an equivalent western engineer. Thus there was considerable cost saving to the customers. Not only were Indian software engineers cheaper to hire but their work was also of good quality. To convince the clients about quality many software companies obtained certification from the International Standards Organization (ISO). An ISO 9001 [83] certificate was awarded only after auditors inspected the processes used by a software company such as documentation, testing methods, life cycle management etc. All companies entering the export market obtained this certificate. In addition to ISO 9001 certification many companies obtained the certificate issued by the Software Engineering Institute (SEI) of the Carnegie-Mellon University. SEI certifies a company based on the "maturity" of its software development process. The highest level of maturity of the software development process followed by a software company was called the Capability Maturity Model (CMM) level 5 [84]. Attaining CMM level 5 is considered a challenge by software companies. The Motorola (India) software team was the first team in the world to attain this maturity level in 1993. ISO 9001

certification is essential for bidding for software projects in Europe whereas the CMM maturity level is valued more in the USA. Following Motorola several Indian software companies got CMM level 5 certification. (CMM level 5 group companies are an elite group.) It is estimated that only 250 companies in the world have this certification in 2012 out of which 166 are in India. Correct statistics are hard to obtain [85]. The CMM level 5 certification and the ISO 9001 certification require emphasis on well documented processes which every software engineer in the organization is expected to follow. They also require the software company to develop good project management capability. The process orientation allowed companies which were recruiting large numbers of employees each year to quickly train them to become productive members of a development team. Staff attrition also could be managed better due to the disciplined software development process.

Another fortuitous circumstance which occurred during this period was the Y2K [86] problem or the millennium bug. Software developed during the 70s and 80s (mostly in COBOL) used 2 digits to represent the year field. This was done to save memory space which was at a premium in early computers. It was assumed that the leading two digits were 19. Consequently when the year changed to 2000 (which also happened to be a leap year unlike 1900) these programs would give unexpected results. Thus all these programs required identification of the problem and appropriate changes. This bug fix was labour intensive. There were not enough software engineers in the USA and Europe to fix the bug and it had to be outsourced. This was a godsend opportunity to many fledgling software services companies in India. Many of them earned the goodwill of clients by not only fixing the Y2K bug but also improving the software (when appropriate) at no extra cost to the customers. This opportunity gave many software services companies entry to the Fortune 500 companies and enabled them to get software development contracts later. In fact the Y2K problem which was considered a big threat in the mid 90s did not become one partly due to a large number of software professionals working diligently in India between 1993 and 1999 fixing the bug. It is estimated that 23% of the revenue of INFOSYS (a major software firm) in 1997 was for fixing the Y2K bug [4, p.349].

Another important factor which enabled Indian software companies to get a foothold in the US software development market was the presence of a large number of Indians in the Silicon Valley who were occupying influential positions in the US companies. IIT graduates of the 60s and the 70s had gone to the USA for higher studies. Most of them had obtained Master's and Doctoral degrees in the Universities in the USA and chose to settle down there as opportunities in India, in their perception, were limited. There was raging debate in India whether public money spent on educating them was wasted. The "brain drain" of the 60s and the 70s became "opportunity gain" in the 90s when India liberalized its economy. The influential Indian diaspora provided an opportunity

to many fledgling Indian software companies to get small contracts at the beginning which grew as the companies delivered good quality software applications. Many non resident Indians also set up software companies in India with their relatives and provided capital, know how, and introduction to clients in the USA.

Another big incentive to start software companies was the low initial investment with STPs providing even offices and workstations at low rentals. Venture capital was unknown in India before 1988. In 1988 the Unit Trust of India (a mutual fund controlled by the government) collaborated with ICICI bank (a private sector bank) and established a venture capital fund called Technology Development and Information Company of India (TDICI) which started funding IT startups [121]. This was followed in the 90s by Canbank Venture Capital Fund and some state governments such as Gujarat, Andhra Pradesh, Punjab and Kerala setting up venture capital funds. This was an additional incentive for many first generation entrepreneurs to enter the IT business.

Besides the Y2K problem, the European Union announced in 1995 that the Euro will be used as the common currency of the Union from 1 January 1999. This required banks and other financial institutions to convert their programs before 1999 to accommodate the Euro. All legacy programs had to be modified. This was a labour intensive job and provided software conversion contracts to numerous Indian software companies.

The government policy of allowing foreign direct investment resulted in many multinational firms setting up software development centres in India. For example, American Express established a centre in Mumbai in 1994 to carry out back-office functions such as accounts receivable, payroll processing, inventory control etc. IBM which wanted to re-enter India partnered with the Tata group and started TATA-IBM in 1992 with 50% stake. Many other companies such as HP, Oracle and GE Capital began operations in India. The liberalization of communications encouraged over 200 software services companies to set up private dedicated satellite links with their clients to develop and maintain software for them.

The period 1991-1997 was a period of double digit growth. In Table 2 [82] we give the software services export figures for the period 1990-1991 to 1997-1998

The period 1991-1997 ended in a highly optimistic note with the software industry in a strong position. The export earning of software services companies were significant and the voice of NASSCOM was strong and it got the ear of the government.

Table 2. **Software Services Export Revenue**

Year	Value in million US Dollars	Growth Percent
1990-1991	128	28
1991-1992	164	28
1992-1993	225	37
1993-1994	330	47
1994-1995	450	36
1995-1996	734	63
1996-1997	1100	49
1997-1998	1759	60

Source: Subhash Bhatnagar [82]

The situation in the hardware front was not as rosy. Almost all computer manufacturers became assemblers. Populated boards were imported. Systems engineering was however very strong. India was in a position to design high performance parallel computers and software systems for them. Texas Instruments which started by designing tools for VLSI design soon found that Indian engineers were talented chip designers. In 1997 they announced a DSP chip code named Ankur (a Sanskrit word meaning Seedling) [64] which was entirely designed in India and was widely used as parts of disk drives and instruments. India got a foothold in the software services export market and also in the high tech area of integrated circuit design and other R and D work. Many multinationals also came to India. In 1994 Oracle set up a software development centre in Bangalore and in 1997 GE Capital International Services started a centre to do back-office services such as finance, accounting, and insurance claims processing (called Business Process outsourcing- BPO). The situation was ripe for further growth.

7. THE PERIOD OF RAPID GROWTH OF THE IT INDUSTRY (1998-2010)

The impact of liberalization of the IT industry and the subsequent recommendations of the IT Task Force in 2000 was felt during this period. The emphasis on hardware, production of computers, and import of computers which held centre stage from 1955 to 1990 had started gradually shifting to software services during 1991 to 1997. The reduced cost of hardware, faster communications, and the emergence of STPs during 1991 to 1997 with subsequent earning of foreign exchange by software service companies led to the policy makers shifting their focus to software. The passing of the Special Economic Zone (SEZ) Act in 2005 allowed duty free import of hardware. Income tax exemption on export earnings for 10 years gave an impetus to a large number of companies to set up units for software and services export. Two hundred and fifty seven software/service companies were set up in SEZ by 2007 [87]. The change in rules allowing a substantial part of export earnings by Indian IT companies to be used for business purposes led to the acquisition of IT companies in Western countries by Indian IT companies. Quite a few Indian IT companies became multinationals with 10 of them listed in overseas stock exchanges. These companies had over 400 delivery centres outside India with presence in 52 countries. The export earning of Indian IT companies which was USD 2 Billion in 1998 grew to USD 50 Billion in 2010 [88].

7.1 POLITICAL ENVIRONMENT

In the general election of 1998 a coalition (called the National Democratic Alliance (NDA)) with the Bharatiya Janata Party (BJP) as the majority partner came to power. In 1998, India conducted an underground nuclear test which led to a diplomatic standoff with the USA leading to an embargo on high tech import from the USA. However, the economies of India and the US were strongly linked with many US multinationals including Microsoft and IBM having operations in India. Soon there was a thaw in the Indo-US relations with the US President Bill Clinton visiting India in 2000. By 2001 a number of US sanctions were lifted. The BJP led NDA was pro-active as far as Information Technology was concerned and a task force was appointed to prepare an IT action plan to give impetus to this field. The export earnings of IT companies were growing around 35% each year. In fact in 1998, Atal Bihari Vajpayee, the Prime Minister of India, declared “IT is India’s Tomorrow” at the Bangalore IT.Com 1998 conference [89]. The election in 2003 was fought with the NDA’s slogan, “India Shining”, but the coalition was defeated, partly due to the fact that the benefits of economic growth had not spread evenly and the rural poor felt left out and did not appreciate the slogan.

The Congress party returned to power as a senior partner of a coalition called the United Progressive Alliance (UPA). Manmohan Singh who as Finance Minister in 1991 had ushered in liberalization became the Prime Minister. Thus

the liberalized policies continued and the economic growth in 2007 was 9.4%. The UPA won the election in 2008 also and is currently in power. By 2008 the relationship between the USA and India improved considerably. The US President George Bush signed the "Civil Nuclear Deal" with India [90] in 2008 and lifted the 30 year sanctions on trade in nuclear material and so called "dual use technologies" which included high performance computers and certain types of software such as high end CAD/CAM tools.

7.2 GOVERNMENT POLICY AND INITIATIVES

Soon after the NDA came to power it set up an Information Technology task force with the Deputy Chairman of the Planning Commission as its chairman. The committee included bureaucrats, politicians, industry representatives, and academia. The terms of reference were very broad. The objective given to the committee was to suggest wide ranging reforms and incentives to the IT industry to achieve a target of export earnings of USD 50 billion by 2008. The task force gave 108 recommendations [91] to the government. A summary of the important recommendations are given below:

- Provision of high bandwidth communication links to IT industries.
- Zero licence fees to start Internet services.
- Removal of the monopoly of VSNL (a public sector company) for providing international gateways for the Internet.
- Allowing private Software Technology Parks to provide infrastructure to small and medium IT companies.
- Allowing Public Call Offices to provide Internet services to the public in addition to telecommunication services.
- Expanding the definition of IT to include IT enabled Services (ITeS) and BPO besides software development.
- Eliminating import duty on disks, displays and many other items.
- Eliminating import duty on capital goods used to manufacture IT products.
- Freeing software companies from inspection by numerous government and local body inspectors such as boiler inspectors, excise inspectors, labour inspectors, environment/pollution control inspectors etc. who were a source of irritation and corruption. The government realized that they were irrelevant to the IT industry.
- Enabling state controlled banks to provide venture capital to IT industries without collateral.
- Requiring nationalized banks to provide working capital requirements to the IT industry on concessional terms, treating them as priority industry.
- Allowing "sweat equity" and "employees' stock option plans" which were alien to other industries in India. This required change in company laws.

- Easing the use of foreign exchange earned by software companies for business purposes without getting prior approval of the Reserve Bank of India.
- Providing government subsidies for IT companies to participate in international trade shows.
- Setting up a National Council on IT education to improve education standards and creating a pool of good educators.
- Setting up one Indian Institute of Information Technology in each state to increase the available human resources pool.
- Providing Internet connectivity to all Universities, colleges, hospitals and selected high schools.
- Stipulating IT literacy as essential requirement for all future jobs in the government. Making suggestions for training programmes for the existing staff in government departments.
- Suggesting framing a national policy on information security, privacy and data protection.
- Suggesting passing of cyber laws by the Parliament.

Most of the recommendations were implemented within a short time.

Besides the IT task force which submitted 108 recommendations to the government in August 1998, another group was formed to recommend reforms to provide a hospitable environment for the growth of the IT hardware industry [92]. Whereas the software industry is human resource intensive, the hardware industry is capital intensive. Their infrastructure needs are more. Customs clearance of hardware took time and availability of power, water, and transport facilities were below par. Liberalizing access to capital, customs clearance, and simplifying rules for Export Processing Zones to set up hardware companies was recommended. In spite of these the hardware companies' growth was slow and they did not grow as fast as the software companies. A third part of the Information Technology Task force's report was on long term policies.

The other major action taken during 1998-2010 was the expansion of education in IT related areas and engineering. Private corporate bodies were allowed to set up Universities in 2002 with relevant acts [93]. Even though private colleges were in existence earlier, during this period private Universities and private colleges proliferated under this policy. A National Board of Accreditation for accrediting engineering colleges was formed by the All India Council for Technical Education (AICTE) [94], a statutory body that controls technical and management education. The University Grants Commission which controls Universities also set up a National Assessment and Accreditation Council to inspect institutions, grade them, and accredit them. These initiatives were essential to control the quality of students graduating from private educational institutions which were proliferating.

In 2000 the Parliament of India passed the Information Technology Act 2000 which was to catalyze e-commerce [95]. The Act gave legal status to e-mail correspondence, allowed use of digital signature in documents, permitted setting up of public key certifying authorities, and allowed archiving legal documents in electronic form. Besides these it also specified punishment for various cyber crimes such as hacking private databases, introducing viruses, publishing objectionable material, and financial frauds. In addition, it created a legal framework to try cyber crimes. The act was amended in 2008 to rectify some loopholes in the earlier law. India was indeed one of the first few countries to pass IT laws [96].

It was recognized that information technology is closely related to communication technology. The Department of Electronics was merged with the Ministry of Communications to create a new Ministry of Communication and Information Technology. A new telecommunication policy was announced in 1999 [97] liberalizing this area and allowing greater role for private players. Following this a national broadband policy was announced in 2004 [98]. The aim was to increase broadband availability to at least 20 million individuals by 2010. To promote this, Digital Subscriber Link (DSL), fibre to home, cable networks, and Direct to Home satellite transmission (DTH) were allowed to be installed by all licenced ISPs. To promote WiFi, the 2.4 to 2.8 GHz band was delicenced for low power outdoor use. Low power indoor use of the 5.15 to 5.35 GHz band was also delicenced. Voice over IP (VoIP) was still not legal. After prolonged discussions VoIP was finally legalized in 2008 by the Telecommunication Regulatory Authority of India (TRAI) [99].

7.3 STATUS OF THE IT INDUSTRY

By 2010 Indian IT companies were recognized as world class based on their performance. From low level testing type projects, the major companies graduated to develop end-to-end applications such as processing credit card payments. Instead of costing based on manpower cost + expenses + profit, companies were now taking fixed price contracts to deliver application software of requisite quality in specified time. Indian companies were not any more competing for software services contracts based on low cost but on quality and timely delivery [80]. The greatest advantage Indian IT companies now had was project planning experience and process maturity as evidenced by their attaining SEI's CMM level 5 certification. In 1999, 6 out of 12 CMM level 5 certified companies in the world were in India. By 2010, more than 400 of the Fortune 500 companies were clients of Indian software companies [100]. CMM level 5 certification has been obtained by 166 IT companies in India.

Besides the growth of software development companies there were also some new businesses that depended on software and fast worldwide communication

which grew rapidly during this period. They were IT enabled services (ITeS) and Business Process Outsourcing (BPO). IT enabled services included tasks such as checking insurance claims, filling income tax returns, medical transcription, remote support on bug fixing of software, call centres etc. The call centres operate 24 x 7 for worldwide customers and require language proficiency mostly in English and some European languages.

Business Process Outsourcing (BPO) is primarily performing the back-office work of a number of organizations, the largest segment being banks and insurance companies. The back-office work was typically accounts receivable, payroll processing, account reconciliation, inventory management, and similar jobs. American Express was the first organization to start BPO work in India in 1994 followed by GE Capital International Services in 1997 [101]. The success of these pioneers induced a large member of Indian companies to start BPO Centres for foreign clients in SEZs as the profit earned at these locations was tax exempt. The cost of starting a BPO was low as the cost of computer hardware as well as that of communication fell rapidly. The only requirement was trainable human resources with good knowledge of English (which was available in reasonable numbers) and identification of overseas clients. BPOs were established not only by Indian companies performing tasks for off-shore clients but also by many British and American companies who shifted their back-office data processing to India as they could get better quality employees and infrastructure at a lower cost. The falling cost of communication immensely helped the expansion of BPOs.

Another significant development in India during this period was the establishment of research, design and development centres of several multinational companies. The centres were being set up in India to take advantage of the availability of high quality computer science graduates at reasonable cost. The availability of good quality office space in metros and improved communication facilities was another incentive. In 1998 Microsoft established a software development centre in Hyderabad and Motorola a design centre in Delhi. The policy change of allowing companies to have 100% ownership without the need for an Indian partner was vital (the reader may remember that IBM left India in 1978 as they were asked to dilute equity to 40%). IBM which had returned to India in 1992 as an equal partner of the Tata group bought off Tata group's share and became the sole owner of IBM (India) in 1999. By 2010 the number of employees of IBM in India was around 85000, second only to the number of its employees in the USA. By 2010 other large multinationals operating development centres in India were: Accenture, CISCO, -DELL, GE, Oracle, Adobe, SAP, Philips, HP, and Google. In fact the India centre was the first Research and Development Centre of Google outside the USA. Texas Instruments which had started work in India in 1985 developing software tools discovered that the quality of their employees in India was as good as

those in other countries. They started end to end design of integrated circuits in their India Centre. In 2003 they designed a new DSP chip entirely in India and in 2008 a single chip for an ultra low cost mobile handset. This was followed by many new chips and their employee numbers grew to around 1500 by 2010. TI's example is typical of multinationals which came to India. They came at first to take advantage of the low cost, they expanded when they found that the quality of engineers was good and later they invested for innovation. By 2008, TI had obtained 309 patents from their India centre. Other microelectronics design and R and D centres were also set up in India during this period by companies such as AMD, Philips, Intel, and ST Microelectronics (a European multinational). The multinationals operating in India obtained over 1600 patents during the period 2006 to 2010 [102].

Another business which started during this period was "laboratory for hire". In this model Indian companies provided physical infrastructure, trained engineers and project leaders for developing prototypes of products for small and medium businesses outside India. The product idea and the IP rights of the product belonged to the customer. The Indian laboratory developed a prototype and tested it. In some cases even a new integrated circuit or programmable logic system was delivered as part of the contract [103].

An important impetus for the growth of IT during this period was the entry of venture capitalists and angel investors in sizable numbers. A group of successful Indian entrepreneurs from the Silicon Valley in the USA established TiE (The Indus Entrepreneurs) [111], a global nonprofit organization to foster entrepreneurship. TiE established chapters in many cities in India to encourage young IT professionals with good ideas to start businesses providing both funding and managerial assistance. In addition many foreign funds entered the scene. In 2007, 905 deals worth USD 5.3 Billion were signed besides 748 Internet specific deals worth USD 4.6 Billion [112].

On the hardware side commodity PCs and laptop manufacture slowly faded out. They were assembled from boards and other parts imported from China, Taiwan etc., and sold by HP, Dell, Asus, Acer, and other multinational companies. Indian "manufacturers" such as HCL, WIPRO, and Zenith were also assembling machines with imported kits but their volumes were low as they could not compete in quality and mass manufacturing capability of the multinational companies.

India was however quite active in designing high performance parallel computers. CDAC designed a parallel machine named PARAM PADMA in 2003 which used 248 processors and a proprietary interconnection network. Its peak speed was 992 gigaflops and it was ranked 171 in the top 500 list of high performance computer in the world [104]. Computatinal Research Laboratories of the Tata group also designed a high performance computer which they named

Eka (Sanskrit for one) in 2007. It used a high speed 20 Gbps infiniband interconnect to connect 1800 dual quad core 3GHz processors with 16 GB RAM each. It had 80TB of external storage and a parallel file system with 5.2 Gbps throughput. Its peak speed was 172 Teraflops and sustained speed was 133 Teraflops. It was rated the fourth fastest computer in the world when it was announced in 2007 [105] and the fastest in Asia. It was made accessible via an Internet cloud in 2010.

There were also innovations in hardware design. A multilingual hand held low cost computer called Simputer was designed in 2000 by a group from the Indian Institute of Science, Bangalore, and Encore Software Ltd., Bangalore. It received worldwide attention [113] for its innovative design. It was, however, not a commercial success. Vinay Deshpande and Shashank Garg of Encore Software Ltd. along with me, when I was a Director of the company, designed a low-cost tablet computer called Mobilis in 2004. Even though it received wide attention and was praised for its innovation, it was again a commercial failure due to the inordinate delay in bringing it to the market and inadequate financing [114].

Another important development during the period 1998-2010 was the increasing use of computers in all walks of life. All banks computerized their customer services as well as back-office functions. The feeling that computers would lead to reduction of job opportunities was finally put to rest. The spread of banks to every nook and corner of India, the increase in volume of transactions, and the number of customers could not have been handled manually. ATMs were introduced by private banks in 1998 and all nationalized banks soon after. All ATMs are now networked and a debit or credit card issued by any RBI approved bank can be used in any ATM anywhere in India. With the advent of the Internet and the passing of the IT Act in 2000, anywhere anytime banking using the Internet was adopted by all the major banks. With the rapid spread of mobile communication, mobile banking started in 2010.

E-Governance grew rapidly during this period. Citizen services such as property registration, paying property taxes, and obtaining various certificates from the government used to be manual, slow, and prone to corruption. Use of computers expedited these services and reduced corruption. States vied with one another to provide computer based services. Public-private partnership to provide citizen services grew rapidly. In this model a private company does the programming, maintains the infrastructure, and collects a small fee for the service from the user. The government audits and authenticates the service. With the advent of the Internet the procedure has been further simplified. Property tax can now be paid from one's home using a PC and a credit card [106]

The Income Tax department is also now fully computerized. By 2010 e-filing of income tax returns by companies was made compulsory [122]. Individuals are

also encouraged to e-file returns. By 2013 it is expected that it will become compulsory for everyone to e-file returns.

Reservation of tickets in trains which was first introduced in 1986 was a land mark in changing the perception of the general public about computerization in India. The system became web based in 2006 and by 2010 passengers could reserve their seats on any train and get the tickets printed at their homes using their Internet connected PCs and credit cards. In fact by 2010 airlines tickets, bus tickets, theatre tickets, and many other tickets could be booked using the Internet [107].

All these could not have been achieved without educated human resources. There was a rapid expansion of engineering colleges between 1998 and 2010. The ground work for the expansion of IT education was laid in 1980 itself with the introduction of MCA courses and the expansion of B.Tech courses as per Rajaraman committee recommendations [59]. During the period 1998 to 2010 there was a rapid growth of private engineering colleges and colleges offering MCA courses. In 1998 the number of engineering students was around 135,000 and in 2010 it grew to 1,300,000, a growth of almost 10 times. The number of MCAs graduating in 1998 was around 7000 whereas it jumped to 120,000 by 2010 [108]. Added to this were non-formal vocational courses given by commercial institutions such as NIIT and Aptech. The DoE started accrediting private training institutes in 1995 [59, p.383] with a scheme called DOEACC. DOEACC later became an examining body giving certificates named 'O', 'A', 'B', and 'C' levels based on the competence of the candidates who wrote these examinations. This non-formal scheme also added to the human resource pool. There was also a large pool of graduates with B.Sc. and BCA (Bachelor of Computer Application) degrees who were suitable for BPOs and ITeS companies. The IT companies' common complaint was that there were not enough employable graduates with computer science degrees. Instead they recruited all engineering graduates with aptitude in computing; however they could not be directly placed as members of project teams. All major IT companies had in-house training programmes ranging from 12 weeks to 6 months. The training schedule was gigantic as every major software company was recruiting around 8000 graduates each year. Another problem faced by the IT companies was "attrition" with increasing demand for experienced engineers and that of project leaders. The average attrition rate was 15 to 20%. With many of these companies having a work force of the order of 120,000 the replacement numbers themselves were over 15,000 each year.

A weakness in the education system was the non-availability of post graduate engineers (Masters and PhDs) who were now required to teach and for Research and Development oriented jobs. The number of Master's Students in Computer

Science graduating per year is around 2000 and PhDs around 100. This is inadequate and a large expansion is required in this area.

8. CONCLUSIONS

What are the lessons India learnt during the period 1955-2010? Can the growth of computing during the period 1991-2010 be sustained? As a poor country with a low demand for computers it was strategically incorrect to try to design computers starting at the component level during 1970-1980 and hope to be completely "self-reliant". It would have been wiser to spend the available scarce resources in systems engineering and to build computers using sub-assemblies during the early stages of development. This is particularly true in the area of computers where huge investments were being made by the richer countries in research and development with consequent fast changes in technology and rapid obsolescence. This was realized only in the mid 80s and the consequent policy change led to a rapid growth of computer availability. The fear of unemployment which was in the backdrop while taking decisions regarding the use of computers in the 70s was misplaced. In a country with a huge population and a voluminous data processing requirement one cannot manage without computers. This was amply demonstrated when the Indian Railways computerized the reservation of tickets on trains in 1986 and the general public saved many hours of standing in queues to buy tickets. In effect this project changed the mindset of both the general public and the politicians on computers. The investment made in higher education paid off handsomely. Graduates of IITs set up during the 60s became technology leaders and entrepreneurs not only in India but also in the USA in the 80s. The Department of Electronics along with the Ministry of Human Resources Development took the initiative in the early 80s to increase the human resources availability by starting Bachelors degree programmes in Computer Science and also Master of Computer Applications programme. A teacher training programme was also started in the 80s. Private companies such as NIIT provided vocational training. The DoE also initiated an accreditation programme and administered standardized examinations to certify the vocational courses given by private institutions. These early initiatives provided the human resources which enabled the software industry to take off in the nineties.

Research projects funded by the Government of India and the United Nations Development Program created a large pool of technology leaders, human resources and strengthened institutional infrastructure. The National Informatics Centre, the National Centre for Software Technology, the Centre for Development of Advanced Computing, the Computer Aided Design Centres, and the Centres for Knowledge Based Computer Systems Development, among others, had a big multiplier effect on the return on investments, much larger than the meagre amounts invested. Compared to the investment in education and research the investment made in computer manufacture by the government companies did not have the same multiplier effect. The investment, however, did meet some strategic requirements in defence and atomic energy. A slew of

policy initiatives taken in the mid 80s and the early 90s as a consequence of "liberalization" consisting of de-licensing of hardware companies, liberal import of computers to develop software for export, liberalizing company laws, providing tax incentives for software and services export, encouraging private initiative in setting up educational institutions, establishing STPs, allowing dedicated satellite communications to software companies with their overseas clients, and allowing multinationals to invest in development centres and BPOs led to an exponential growth of IT companies in India. The emphasis on quality certification, systematizing application software development processes, and project management were all essential ingredients for the success of the Indian software services companies in the international market.

In conclusion I have identified the following major problems which need to be resolved for a healthy growth of IT industry in India:

1. Lack of integrated circuit fabrication plants. Good know how is available to design novel ICs including analog-digital system but there are no up-to-date foundries for fabrication.
2. Even though there is a large number of engineering graduates, the quality is uneven. A concerted effort to improve the quality is needed. One initiative which is being taken is the creation of a National Knowledge Network which we will discuss in point 12 below.
3. Due to the rapid growth of educational institutions there is an endemic shortage of good teachers. A big increase in the output of Masters and PhDs, particularly in Computer Science, is required.
4. A large number of faculty positions in the Universities and engineering colleges and even in the IITs are vacant due to the dearth of persons interested in becoming academics. Encouragement in terms of good working conditions and emoluments are needed to attract competent faculty.
5. R and D spending of the Indian software services companies is relatively low. To go up the value chain IT companies have to innovate and invest in focused research. The reduction of cost of communication gave birth to the "offshore" software development model. The recent emergence of the "Computing Cloud" should lead to the next step, namely, providing Software as a Service (SaaS). The rich experience gained in the international market of offering software services should be leveraged to create world class "service products" from India on the "Cloud".
6. A question is often asked why Indian software companies have not produced a world class software product when there is so much software talent in India. There is no simple answer. Product companies need, besides an innovative product, huge investment, marketing, and the willingness to take risks. A company which was initially successful in selling FORTRAN compilers in a protected market in India went bankrupt as soon as imports were allowed as the imported product which had a worldwide market sold compilers at less than half the price of the local product. One of the few notable successes as a

product company in India is TALLY [117] which produced accounting software in 1980. It succeeded as the software was designed keeping in view the accounting practices in India. It was affordable to a large number of small and medium enterprises. This provided the volume essential to amortize the development cost of the product. TALLY was able to continually improve its product by getting feedback from its local users. No foreign competitor understood the nuances of the local accounting practices or could match the price. TALLY later upgraded the product as an Enterprise Resource Planning (ERP) system. TALLY's revenue in 2010 was around USD 40 million and it is now expanding its operations to Africa. The revenue of software service companies are in the range of a few billion US dollars. One can see why the services companies are not too keen to enter the product space with all the attendant risks.

7. The IT industry is currently primarily export driven. Protectionist policies (such as increasing the visa fees for issuing business visas and putting a ceiling on the number of visas issued by some western countries) are having adverse effect on the industry. To mitigate this, large local market should be developed.

8. Over 75% of the current software services exports are to companies in the USA and the UK. The industry needs to explore other markets particularly in Asia and South America to reduce the risk due to slow down of the USA and UK economies.

9. There is poor penetration of IT to the rural areas which constitute 70% of the Indian population. The rural Internet connectivity is estimated to be 2%. Unless the content which can be used by the rural population in the appropriate local language is available attempts to provide connectivity will be futile. The high cost of computers and broad band access (relative to the purchasing power) has been a major impediment in spreading IT to rural areas. Another impediment is the lack of "digital literacy".

10. Even though the DoE has invested in research projects on technology development in Indian languages, the use of Indian languages in computing is not widespread. This is probably due to the perception among the general public that proficiency in English will provide them better employment opportunities and greater mobility.

11. The computer hardware sector has not progressed as fast as the software services sector in India. Innovative hardware product design is feasible as demonstrated by the Simputer and the Mobilis. Production and marketing, however, have been poor. Speed of execution of hardware projects is vital. It is faster and cheaper to outsource production to countries like Taiwan and China which have specialized in computer hardware services. It is also not advisable to embark on hardware product manufacture without adequate finance and excellent marketing abilities. A large assured purchase order from the government would greatly help. However governments all over the world are unreliable customers as Nicholos Negroponte found out in the One Laptop per Child project conceived by him [118].

12. Lastly, the Government of India allocated in 2010 around Rs. 600 billion (around USD 12 billion) to be spent over 10 years to interconnect all research

laboratories and educational institutions in India with high bandwidth (10Gbps) backbone network and at least 1 Gbps “last mile” connection [119]. This infrastructure known as the “National Knowledge Network” (NKN) [120] has an ambitious plan of providing virtual class rooms to spread high quality education and alleviate the dearth of good teachers mentioned earlier in this section. As of now (2012) the project has connected around 850 institutions and has set up 52 Virtual class rooms. The major objective of NKN is to facilitate knowledge sharing and collaborative research among scientists besides sharing resources such as computing power, laboratory instruments, libraries, and data bases. NKN is expected to provide the infrastructure to disseminate information for better health care, improve agriculture by giving expert and timely advice, and improve e-governance by inter-connecting state data networks.

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APPENDIX 1

Time-Line – Development of Computing in India

Year	Important Events
1955	• HEC-2M arrives in India. 16 bit tube/drum machine designed by A.D. Booth at Birbek College, London, and ordered by ISI, Kolkata from the British Tabulating Machines. • Beginning of the design of TIFRAC prototype at the TIFR, Mumbai (R.Narasimhan leads the team).
1956	• HEC-2M installed at the ISI and used to program statistical calculations in machine language.
1957	• Design of a full-fledged computer similar to ILLIAC begins at the TIFR (R.Narasimhan's group).
1958	• URAL-1 a Russian machine installed at the ISI, Kolkata. Has assembly language.
1959	• TIFRAC fabrication completed. • IBM starts manufacturing key punch machines in India.
1960	• TIFRAC starts working. Assembler developed for TIFRAC.
1961	• ISIJU Project to make transistorized computer begins at ISI/Jadavpur University. • First IBM 1401 installed at the ESSO Standard Oil Co., Mumbai.
1962	• TIFRAC dedicated to the nation by Jawaharlal Nehru the Prime Minister of India. • IBM 1401 refurbishing starts at Mumbai.
1963	• IBM 1620 installed at the IIT at Kanpur. First computer with FORTRAN in India. Education using FORTRAN begins. • Bhabha committee set up to review electronics in India.
1964	• IBM 1401 installed in ISI, Kolkata. • A large number of intensive courses on computing given at IIT/Kanpur. • CDC 160A-3600, a large mainframe computer, installed at the TIFR, Mumbai. • First International Conference on Computing held at IIT/Kanpur. Organized by Harry Huskey with financial support from the Ford Foundation. At the end of the conference decision taken to start Computer Society of India.
1965	• 30 IBM 1401s and 12 ICL 1901s installed in India.

	• Computer Society of India registered in Hyderabad.
1966	• Report of the Electronics Committee (Bhabha Committee) submitted (February). • IBM 7044 installed at IIT/Kanpur. • Rupee devalued from Rs.4.5 per USD to Rs.7.5 per USD. Windfall profit to IBM as rentals were quoted in dollars. • ISIJU project complete. • M.Tech program in computers in the Electrical Engineering Department started at IIT/Kanpur.
1967	• ECIL established at Hyderabad by the Department of Atomic Energy to commercialize electronic instruments designed at the Atomic Research Centre at Mumbai. • Dept. of Statistics, Government of India, installs 10 Honeywell computers.
1968	• TCS established in Mumbai by Tata Sons with an IBM 1401. • IBM 1401 installed as I/O computer for the IBM 7044 at IIT/Kanpur. • Narasimhan committee report suggests self-reliant production of small and medium computers within 10 years. Opines no need for foreign collaboration in design and development.
1969	• TDC 12 computer commissioned at the Bhabha Atomic Research Centre,Mumbai. A real-time data acquisition computer. • Committee on Automation set up by the Ministry of Labour, Employment and Rehabilitation (called Dandekar Committee on Automation). • HP Time sharing computers installed in IIM/Ahmedabad.
1970	• Department of Electronics (DoE) established by the Government of India with M.G.K.Menon as its Secretary. • Foreign companies asked to dilute equity. IBM declines. ICL agrees and collaborates with the Bharat Electronics Ltd. (BEL) to manufacture ICL 1901A – 48 computers manufactured. • National conference on Electronics under the Chairmanship of Vikram Sarabhai held at Mumbai to elicit comments on the development of electronics and computers. Self-reliant development of computers in India proposed.
1971	• Electronics Commission established by the Government of India in Delhi as policy making body for electronics and computers with M.G.K.Menon as its Chairman. • IBM 1401 withdrawn in the USA. • 14 IBM 1401s installed by the Indian Railways for accounting, freight etc. • TDC 12 marketed by ECIL.

1972	• DEC 1077 installed at NCSDCT at TIFR with UNDP assistance. Groups in graphics, networks, databases, and compilers formed to do research in these areas. • Panel on minicomputers constituted by the DoE to formulate a strategy for the development of small and medium computers by Indian companies. • Separate Computer Science Programme starts at IIT/Kanpur. Masters and Phd degrees offered. First such programme in India.
1973	• Report of the panel on minicomputers submitted. Opines that minicomputers can be made in India without any know-how being imported from abroad. No collaboration should be allowed. Demand for the period 1974-79 projected around 1400 minicomputers. • Santacruz Electronic Export Promotion Zone (SEEPZ) established in Mumbai to promote export of electronic items and software. • Foreign Exchange Regulation Act passed. • IBM asked to dilute equity again. Declines. • Air Defence Ground Environment Systems (ADGES) design begins at TIFR. Plans to use ruggedized ECIL TDC 316 computers, display devices developed by Tata Electric Company, Radar from Electronics and Radar Development Establishment (LRDE) Bangalore with the user agency, namely, the Indian Air Force giving requirement specifications and test data. Entire system to be developed and fabricated with Indian engineers and Indian made subsystems. • IIT/Madras installs IBM 370/155 with financial assistance from the Federal Republic of Germany. Fastest computer in south India.
1974	• TDC 312 marketed by ECIL (uses imported ICs, local components locally made PCBs, and imported peripherals.) • Regional Computer Centre (RCC) set up at Pune with an ICL mainframe. RCC to give low cost computer time to students and software exporters. • ECIL imports IRIS 55 (from France), a 32 bit computer to expedite software development and reverse engineered to make TDC 332. • Computer Imports for software export policy.TCS uses the scheme to import a Burroughs mainframe computer. • Minicomputer policy not implemented – delayed due to indecision and foreign exchange problems.
1975	• Tata Burroughs established in SEEPZ. Burroughs B1728 and B6738 installed to export software. F.C.Kohli of TCS prime mover of the idea. • DOE issues guidelines for import of computers costing more than Rs. 500,000. Foreign exchange difficulties. • National Informatics Centre (NIC) established with UNDP assistance (USD 4.4 million).

	• TDC 316 produced and sold. • Engineers India installs Ryad 1040 from East Germany to export engineering design software to East European countries. • Ryad 1030, 1020 computers from the USSR also installed for software export to the USSR (Rupee trade with the USSR eases import of machines).
1976	• CMC established by the DoE. • CMS formed by some IBM employees to maintain IBM 1401 computers. • Report on the operation of IBM and ICL by the Public Accounts Committee of the Indian Parliament. Report criticizes companies. • Patni Computers collaborates with Data General Computers for software development. • DoE starts Appropriate Automation Promotion Program (AAPP), later renamed Industrial Electronics Promotion Programme (IEPP).
1977	• IBM announces intention of closing operations in India. • Regional Computer Centre, Calcutta, established with Burroughs B-6738 computer. • Minicomputer policy continues to be in limbo.
1978	• IBM closes operations in June. • CMC takes over maintenance of IBM computers. • IDM, a company formed by ex-IBM employees takes over IBM's data centres and card plant. • Biswajit Nag takes over as Secretary DoE from M.G.K. Menon. • A.S.Rao retires from ECIL. • Minicomputer Policy announced opening the field of computer manufacture to private industry, breaking public sector (ECIL) monopoly. • IIT/Kanpur starts the first B.Tech programme in CSc at an IIT.
1979	• Sondhi Committee on Electronics report suggests liberalization of import of large computers and allowing private sector to enter computer and peripheral manufacture. • Bharat Electronics Ltd. (BEL – a public sector company specializing in defence electronics systems) decides to quit from computer and peripherals development. • 4 companies, ORG, DCM, HCL, and IDM, start manufacturing minicomputers. Adopt UNIX as O.S. • TCS opens Office in New York for software export.

	• Patni Computers develops comprehensive Apparel Development Software Package for Data General Computers. • Regional Computer Centre, Chandigarh established with DEC 2050 system.
1980	• Rajaraman's manpower committee report accepted by the Electronic Commission. A new programme called Master of Computer Applications to be started. Bachelor's programme in CSc to be expanded. • Software services export by a number of companies start primarily by sending software engineers to client sites (pejoratively called "body shopping"). • Tata Research Design and Development Centre (TRDDC) of Tata Sons established (mostly with funding by TCS). • TALLY, an accounting software product company established.
1981	• Rajaraman committee report on import of computers for software export. • P.P. Gupta takes over as DoE secretary from B.Nag. • Decision to use computers in the organization of the Asian Games. Rajiv Gandhi takes this decision. • INFOSYS established. • Wipro markets 8086 based minicomputer (Wipro 86 series). • Reserve Bank of India computerizes clearing houses and ledger posting after agreement with the labour unions that not more than 10% of staff will be displaced. • NIIT starts private computer training school.
1982	• Asian Games held in New Delhi. Organizer Rajiv Gandhi decides to computerize games schedules, event records, result announcement etc. DCM computers used as terminals, networked with HP machines. Entire software developed locally by NIC engineers in 6 months. Seshagiri interacts with Rajiv Gandhi. • Import of Colour television tubes allowed ; colour television arrives in India to telecast Asian Games. • NCST establishes VSAT network with 32 Kbps packet switching. • MASTEK starts software company in Mumbai. • Electronic voting machine using a microprocessor designed and developed in India used in a state election for the first time in the world. • UNDP funding (USD 653,200) for Appropriate Automation Promotion Programme (AAAP) with centres at Delhi, Ahmedabad, Calcutta, and Trivandrum. Training in microprocessor use in automation.
1983	• NCSDCT hived off from TIFR to form NCST.

	• Bank Unions agree to limited computerization in public sector banks.
1984	• Indira Gandhi assassinated. Rajiv Gandhi becomes Prime Minister. Rajiv Gandhi is computer savvy. • Rajiv Gandhi initiates liberalization of computer industry with Seshagiri of the DoE as his informal adviser. • Trade unions observe 1984 as "anti computerization year". • Gateway Design automation starts software development work for export in Delhi • Citibank sets up software development unit in SEEPZ, Mumbai. • Inter-ministerial standing committee (IMSC) formed to regulate computer import and licensing industry. • Railway passenger reservation project given to CMC by the Railways. • Rangarajan Committee on bank computerization gives report. EDP cells in all banks recommended. • SOFTEK first company to develop compilers for COBOL, BASIC, and FORTRAN for locally made computers • CDOT set up to design electronic telephone exchanges by Indian engineers. • CAD Centres at IISc/Bangalore, IIT/Kanpur, IIT/Bombay and Jadavpur University at Kolkata. UNDP grant USD 1.5 million plus Rs.340 million grant from the DoE. • Computer Assisted Literacy And Study in Schools (CLASS) programme launched by the DoE to cover 250 schools all over India. Uses BBC Acorn microcomputers – 4 given per school. The UK government gives UK Pounds 1.3 Million for the project. • Government of India approves setting up of a National Supercomputer Centre at the Indian Institute of Science at Bangalore with a grant of Rs.500 million.
1985	• Department of Telecommunication (DoT) established. • Telephone services corporatized (earlier telephones were monopoly of a government department). • Software export USD 30 million (CMC, TCS, and TBL main contributors). • Texas Instruments facility at Bangalore established to export electronic CAD software using satellite communication with its Dallas Centre in the USA. • ERNET project starts with UNDP assistance. • Sampath committee on education – teacher training programme suggested. • KBCS project funded by UNDP and the DoE. USD 5.2 million + Rs.140 million grant from the DoE. IIT,Madras, IISc,Bangalore, ISI,Kolkata, NCST,Mumbai, TIFR,Mumbai and IIT,Bombay participated.

	• UNDP assisted Microprocessor Applications Engineering Program (USD 1.53 million) – 5 regional centres at Jabalpur, Bangalore, Ranchi, Pune and Delhi.
1986	• VSNL (Videsh Sanchar Nigam Ltd.) set up for overseas communication. • INDONET established by CMC. SNA network with IBM computers and leased lines from the DoT. • New policy on computer software export, software development and training. • Project to computerize reservation of tickets in the Indian Railways completed. Reservation office in New Delhi with 50 windows started. • NIC acquires SX1000 mainframe computers from Japan for software development for government departments. • NIIT starts franchising training centres. • Rajaraman committee submits report to the Science Advisory Committee to the Prime Minister to establish a centre for developing high performance parallel computers.
1987	• Sterling Computers sells PCs for Rs.29, 000. • TI's Satellite link to Dallas office starts the revolution of "off shore" software development. • Foreign collaboration for branded workstations begins in earnest. Hinditron-DEC, HCL-HP, and PSI-Honeywell Bull established. • NICNET established. • Indian Banks' Association agreement with Bank Unions on Computerization. Standardizes use of UNIX, Micro focus COBOL, and X .25 for networking. IBM PC clones in all banks. • Software India Conference in the USA to promote software companies.
1988	• National Association of Software and Service Companies (NASSCOM) established. • NIC hived off from the DoE and placed in the Planning Commission. • Excise duty exemption for software. • RCC Calcutta machine replaced with CDC 180/840A mainframe. • Cray XMP 14 installed in the Centre for Medium Range Weather Forecasting-number of conditions applies on usage. • Centre for Development of Advanced Computers (CDAC) established in Pune to design and fabricate parallel computers with 1Gflop speed.
1989	• Indian Administrative Service officer takes over from technocrats as DoE secretary. DoE becomes a 'non-scientific" department. S.Rajamani IAS takes over from technocrat K.P.P.Nambiar when he retires. • VSNL sets up 64 Kbps link to the USA.

	• NCST connects ERNET to Internet via UUNET. • Electronics Commission abolished. • Datamatics, a software services company, uses satellite link to the USA to export software. • India's software services export reaches USD 100 Million.
1990	• N.Vittal, an Indian administrative service officer, takes over as the DoE Secretary. • Software Technology Parks set up by the DoE with shared satellite communication links to promote software export. • Companies established in STPs expected to export software each year equal to 4.5 times the salary paid to their employees. • MNCs enter India for offshore software development.
1991	• India nearly defaults in repaying loan. Forced by the International Monetary Fund (IMF) to liberalize. Rupee devalued and floated. • New industrial policy – Multi National Companies (MNCs) welcomed. • Reduced tariff, simplified procedures, and devalued Rupee attract MNCs. • NICNET used to disseminate results of general elections. • Export of software USD 164 million. • IIS is the first software services company to get ISO 9001 Quality Certification. • Software "development centres" set up for individual Fortune 500 companies by TCS (Each centre secure). • National Supercomputer Centre at the IISc, Bangalore starts functioning with a Cyber 992, 2 CDC4360, a VAX8810, 9 IBM6000/580s connected with a fibre optic net to work in parallel, 48 IBM RS6000/340, 24 Silicon graphics workstations, 25 Sun workstations, and a campus-wide fibre optics network. • CDAC completes design of PARAM parallel computer with 1 Gflop speed.
1992	• VSNL introduces 64 kbps leased line services. • Tata group and IBM form a 50:50 joint venture company. • Software product Flexcube for banks developed by Rajesh Hukku of IFlex.
1993	• EDI introduced by VSNL. • Private software companies allowed dedicated satellite links with customers in the USA. • Motorola India first company in the world to get CMM level 5 certification for software quality.

	• Import of software packages allowed on regular duty. Duplicating copies allowed. Duplicates permitted to be sold in the local market and royalty less than 30% of the local price allowed to be paid to the owner of the package. • INFOSYS becomes a publicly listed company • Indian Satellite Development Centre at Bangalore installs a distributed computer system with 9 IBM RS6000/530s, 9 RS6000/220s and 33 RS6000/220s.
1994	• Government monopoly in telecommunication ends. Private companies allowed starting mobile communication services. • American Express sets up Business Process Outsourcing Centre in Mumbai. • 200 satellite links installed by software companies to facilitate offshore software development. • Quality consciousness makes software companies obtain ISO/CMM certification. • Oracle sets up development centre in Bangalore. • Indian copyright act amended – stiffer penalties for infringement.
1995	• First commercial Internet service started by VSNL. • 100% tax holiday for software export earnings. • Private e-mail service introduced (non Internet). • DoE launches programme to accredit private computer training institutes due to proliferation of below par training institutes (named DOEACC scheme).
1996	• NASSCOM sets up Special Interest Group (SIG) to solve Y2K problem. Indian software companies advertised as Y2K solvers. • Indian software companies improve systems while fixing Y2K bug at little extra cost as strategy to get customers. • Rediff.com established – first e-commerce portal in India. • Software export reaches USD 1 Billion.
1997	• Digital Signal Processing chip “Ankur” designed by TI India centre at Bangalore. • Compaq and IBM overtake sales of PCs by local manufacturers. • 23% of INFOSYS revenue due to Y2K. • GE Capital International Services starts back-office services centre.
1998	• Prime Minister of India declares “IT India’s Tomorrow”. • IT task force set up by the government – comes up with 108 recommendations to promote IT among which is setting up of one Indian Institute of Information Technology in each state. • 109 companies receive IS0 quality certification.

	• WIPRO the second IT company in India to get CMM level 5 quality certificate. • IIIT/Allahabad established. • VSNL establishes connection to Global One's 1400 points of presence worldwide. • Microsoft Software Development Centre started at Hyderabad. • Motorola Design Centre established in Delhi. • IBM Research Centre set up in New Delhi.
1999	• INFOSYS listed in NASDAQ. • IBM sets up fully owned subsidiary in India. Tata's stake in TATA- IBM bought by IBM. • 100% Foreign Direct Investment in IT allowed paving way for MNCs entry into India. • 6 out of 12 SEI CMM level 5 companies in India. • Nationwide linking of Railway Reservation System.
2000	• IT Act 2000 passed by Parliament to facilitate e-commerce. • Software export reaches USD 5 billion. • HP Global sets up BPO in Bangalore. • 12 Software Technology Parks host 1196 software companies. • Startup company Spectramind gets venture capital funding of Rs. 1 billion (USD 23 million) to set up back-office to process transactions of Internet portals worldwide. • Private companies allowed setting up international gateways.
2001	• Tata group takes over 51% of CMC Ltd. from the government. • Tata group takes over VSNL. • 10 companies obtain CMM level 5 certificates. 14 companies obtain CMM level 4 certificates. Dell sets up R&D centre. • Simputer, a hand-held multilingual computer, designed by a group of IISc and Encore Software Ltd. engineers at Bangalore. Attracts worldwide attention. • Accenture starts centre in Mumbai.
2002	• Agrawal-Kayal-Saxena algorithm:"Primes in P" attracts worldwide attention. • National Institute for Smart Governance set up in Hyderabad (joint initiative of NASSCOM, Government of India and Government of Andhra Pradesh). • Internet based booking of tickets on the Indian Railways.

2003	• Bharati Airtel (largest mobile telephone provider in India) outsources all IT work to IBM India. • CDAC's PARAM PADMA ranks 171 in top 500 high performance computers. • High performance DSP chip designed at TI India at Bangalore. • Software Technology Parks India (STPI) centres across India reach 44. • Yahoo sets up R and D Centre at Bangalore (first outside the USA).
2004	• National E-Governance plan announced. • General Elections held using only Electronic Voting Machines (1,075,000 EVMs deployed all over India). • TCS, INFOSYS and WIPRO all cross USD 1 Billion revenue. • TCS becomes a publicly listed company. • Government of India announces Broadband Policy; fibre to home, DSL, cable to home etc. Targets 40 million Internet users and 40 million broadband users by 2010. • Google sets up first R&D Centre outside the USA in Bangalore. • IBM acquires Daksh, the largest Indian BPO company. • Number of employees in IT industry reaches 1 million. • State Wide Area Network for each state to be set up with minimum bandwidth of 2Mbps. • Mobilis, a low cost mobile tablet computer designed by Encore Software Ltd., Bangalore, attracts wide attention.
2005	• Oracle acquires IFlex an Indian Banking software product company. • Special Economic Zone (SEZ) Act passed. SEZ defined as "specifically demarked duty-free enclave deemed to be foreign territory (out of customs jurisdiction) for trade, duties and tariffs".
2006	• CISCO establishes Globalization Centre East in Bangalore • IBM announces plans to invest USD 5 billion in India. • SAP (German ERP major) announces USD 1 billion investment in India over next 5 years. • India's software and services export revenue reaches USD 10 billion.
2007	• 257 IT companies set up in SEZ. • Special incentive package announced by the Department of Information Technology to encourage investments in semi-conductor fabrication industry. • EKA supercomputer fourth fastest in the world and fastest in Asia built by the Computational Research Laboratory of the Tata group.
2008	• TI (India) designs single-chip solution for ultra-low-cost mobile handset.

	• Accenture opens Technology lab in Bangalore (Fourth in the world after the USA and France). • 2G spectrum allocation on first come first served basis. • IT (amendment) Act passed by Parliament to strengthen IT Act 2000. • National Knowledge Network project started by the Government of India.
2009	• IBM has second largest workforce in India after the USA. Will invest USD 100 million for global mobile services research in India. • SAP's third co-innovation lab in Bangalore (other labs in Palo Alto and Tokyo).
2010	• IT exports including software, services and BPO reaches USD 50 billion. • IT domestic revenue USD 24 billion. • 55% of the global outsourcing market sourced from India. • Indian IT companies present in 52 countries and have 400 of the Fortune 500 companies as clients. • Direct employment 2.4 million in IT and 8.2 million in support services. • 6.5% of GDP earned by IT industry. • Rs.600 billion allocated over a 10 year period for the National Knowledge Network.

APPENDIX 2

Time line—Political and Economic history of India

Year	Important Events
1947	India becomes independent from the British. Partitioned into India and Pakistan.
1950	India becomes a republic after adoption of a constitution. Planning Commission constituted to guide Indian economy towards a planned development. Resource allocation determined by the planning commission.
1951	First five year plan (1951-1956) formulated. A budget of Rs.235.6 billion (1 USD = Rs.4.8) allocated. Focus on irrigation, energy, transport and communication.
1952	First general elections held. Congress party gets absolute majority. Jawaharlal Nehru becomes the first Prime Minister of India.
1954	Panch Sheel (Five Principles of Peaceful Co-existence) treaty signed with China.
1955	Bandung conference of non-aligned nations held.
1956	States re-organized on linguistic basis. Second five year plan (1956-1961) begins with an allocation of Rs.480 billion. Emphasis on heavy industry (five steel plants set up) and big dams (Bhakhra-Nangal in Punjab, Hirakud dam in Orissa).Funds allocated to start IITs and give scholarships for higher studies abroad to talented scientists and engineers.
1957	Second General Elections held. Congress party gets majority. Jawaharlal Nehru continues as the Prime Minister.
1959	Dalai Lama flees Tibet and comes to India. Border dispute with China.
1961	Third five year plan (1961-1966) launched.
1962	Border war with China. China disputes McMahon boundary line drawn by the British. China occupies some border areas. 3rd General Elections held. Congress party wins and Jawaharlal Nehru continues as the Prime Minister.
1964	Jawaharlal Nehru dies. Lal Bahadur Shastri becomes the new Prime Minister.
1965	War with Pakistan over Kashmir. Green revolution started. 2 years of draught causes near famine conditions.
1966	Tashkent peace agreement with Pakistan. Lal Bahadur Shastri dies. Indira Gandhi becomes the Prime Minister of India. 3rd five year plan ends. 4th plan postponed due to economic crisis caused by draught. PL-480 plan of

	the USA – wheat sent from the USA – paid in Rupees to be spent in India. Rupee devalued from Rs.4.80 per USD to Rs.7.50 per USD.
1967	4th General Elections. Congress party wins and Indira Gandhi becomes the Prime Minister.
1969	4th five year plan (1969-1974) launched. Green revolution – increasing food production using hybrid seeds and fertilizers gets prominence. 25 banks nationalized. Congress party splits. The faction led by Indira Gandhi named Congress (I).
1971	Civil War in East Pakistan. Indo-Pakistan war over exodus of population from East Pakistan to India. Pakistan defeated. Erstwhile East Pakistan becomes Bangladesh, a new independent country. The US President Richard Nixon's support to Pakistan leads to ceasefire in the western front. 5thgeneral elections held. Congress (I) party wins and Indira Gandhi becomes the Prime Minister
1972	Shimla peace agreement with Pakistan signed after the ceasefire. Kashmir problem unresolved. New patent law enacted helping drug industry.
1973	OPEC quadruples oil prices. Causes serious foreign exchange problem for India. Foreign Exchange Regulation Act (FERA) enacted.
1974	Nuclear test conducted by India at Pokhran. India becomes 6th nuclear power. Leads to high tech embargo by the USA and the West. 5th five year plan (1974-1979) launched.
1975	Internal emergency declared by Indira Gandhi when her election was ruled invalid by the Allahabad High Court. Civil rights suspended, opposition leaders arrested.
1977	Emergency rule ends. 6th general elections held. Congress party loses an election for the first time after independence. Coalition government formed by the Janata Party with Morarji Desai as the Prime Minister. 5th plan suspended.
1978	Dissentions among the coalition partners. Janata Party government falls. Revised 5th five year plan (1978-83) drafted before the fall of the government.
1979	Caretaker government. Elections called.
1980	7th General elections held. Congress party wins. Indira Gandhi becomes the Prime Minister. New 6th five year plan (1980-85) launched. 20 point programme announced to remove poverty (Political slogan).
1984	Indira Gandhi assassinated. Rajiv Gandhi becomes the new Prime Minister. Small steps towards liberalizing the economy. 8th General election held. Congress party wins.

1985	7th Five year plan (1985-1990) launched.
1989	9th General elections held. Congress party defeated. Coalition government formed with V.P.Singh as the Prime Minister.
1990	7th Five year plan ends. 8th plan postponed.
1991	V.P.Singh's Government falls. Rajiv Gandhi assassinated during the election campaign. 10th General elections held. The Congress party wins. India faces balance of payments crisis. Avoids payment default. Economic reforms initiated. Rupee devalued to Rs.26 per USD from Rs.13 per USD. Rupee floated. Starts losing value gradually.
1992	8th Five year plan (1992-97) launched. New economic policy announced with Manmohan Singh as the Finance Minister. Market reforms and tax reforms. Economic growth improves.
1996	11th General elections held. No party gets majority. Political instability. Janata party forms government with the support of the Congress party.
1997	9th Five year plan (1997-2002) launched in spite of instability. Government falls.
1998	12th General elections held. National Democratic Alliance (NDA) with the Bharatiya Janata Party (BJP) as the majority party forms a coalition government. Nuclear Test carried out inviting sanctions by the USA. Peace deal with Pakistan's civilian Government.
1999	Military takes over in Pakistan and starts undeclared war over Kargil in Kashmir. India wins – peace declared. NDA Government falls as one partner withdraws support.
2000	13th General Elections. NDA wins with the BJP as the major partner. Atal Bihari Vajpayee becomes the new Prime Minister. Population grows to 1 billion. The US President Bill Clinton visits India. Thaw in Indo-US relation. Liberalization of economy continues. IT Industry gets favorable treatment.
2002	10th Five year plan (2002-2007) launched.
2003	First launch of high power rocket. Capable of placing satellites in orbit.
2004	14th General Elections held. NDA looses. United Progressive Alliance (UPA) with the Congress party as the majority partner comes to power. Manmohan Singh becomes the Prime Minister. India's economic growth story intact.
2006	Chinese Prime Minister visits India.
2007	First commercial satellite launch by India – launches Italian satellite. Economic growth 9.4% of GDP. 11th five year plan (2007-2012) launched.

2008	The US President George Bush signs civil nuclear deal with India lifting 30 years sanctions on nuclear and high tech trade by the USA. Lunar probe launched successfully by India.
2009	15th General elections. UPA with the Congress party as the major party wins. Manmohan Singh continues as the Prime Minister
2010	(British) Commonwealth Games held In New Delhi.

LIST OF ACRONYMS

ADGES	Air Defence Ground Environment System
AICTE	All India Council for Technical Education
AREN	Army Radio Engineering Network
BARC	Bhabha Atomic Research Centre
BEL	Bharat Electronics Ltd.
BJP	Bharatiya Janata Party
BTM	British Tabulating Machines
BPO	Business Process Outsourcing
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing/Management
CDAC	Center for Design of Advanced Computers
CDC	Control Data Corporation
CDOT	Centre for Development of Telematics
CMC	Computer Maintenance Corporation
CMM	Capability Maturity Model
DAE	Department of Atomic Energy
DEC	Digital Equipment Corporation
DoE	Department of Electronics
DoS	Department of Space
DoT	Department of Telecommunications
EC	Electronics Commission
ECIL	Electronics Corporation of India Ltd.
ERNET	Education and Research Network
EVM	Electronic Voting Machine
GDP	Gross Domestic Product
GIST	Graphics and Intelligence based Script Technology
GOI	Government of India
IAS	Indian Administrative Service
IBM	International Business Machines
ICIM	International Computers India Manufacturing
ICL	International Computer Ltd.
IIT	Indian Institute of Technology
IIM	Indian Institute of Management
IISc	Indian Institute of Science
ILLIAC	Illinois Automatic Computer

ISCII	Indian Script Code for Information Interchange
ISI	Indian Statistical Institute
ISIJU	Indian Statistical Institute Jadavpur University
ISP	Internet Service Provider
IT	Information Technology
KBCS	Knowledge Based Computer Systems
KIAP	Kanpur Indo American Programme
MAIT	Manufacturers Association for Information Technology
NASSCOM	National Association of Software and Services Companies
NCSDCT	National Centre for Software Development and Computing Techniques
NCST	National Centre for Software Technology
NIC	National Informatics Centre
NKN	National Knowledge Network
OLPC	One Laptop Per Child
OPEC	Organization of Petroleum Exporting Countries
PCO	Public Call Office
PPP	Public Private Partnership
RBI	Reserve Bank of India
RCC	Regional Computer Centre
SEEPZ	Santacruz Electronics Export Promotion Zone
SEI	Software Engineering Institute
SERC	Supercomputer Education and Research Centre
SEZ	Special Economic Zone
STPI	Software Technology Park India
TDC	Trombay Digital Computer
TIFR	Tata Institute of Fundamental Research
TFRAC	Tata Institute of Fundamental Research Automatic Calculator
USAID	United States Agency for International Development
USD	United States Dollar
Y2K	Year Two Thousand

About the Author

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Vaidyeswaran Rajaraman earned a BSc(Hons) in Physics from the Delhi University in 1952 and joined the Indian Institute of Science, Bangalore, where he obtained a Diploma of the IISc in Electrical Communication Engineering in 1955 and an Associateship of the Institute in 1957 for the research work he did in developing non linear units for an analog computer using which many non-linear engineering problems, otherwise intractable, were solved . He was awarded a scholarship by the Government of India and went to the Massachusetts Institute of Technology, Cambridge, MA, U.S.A, where he earned a Master's degree in Electrical Engineering in 1959. He then joined the University of Wisconsin, where he obtained a PhD in 1961. In 1961 he was appointed as an Assistant Professor of Statistics at the University of Wisconsin where he served till 1962. He decided to return to India in 1962.

On returning to India he joined the Indian Institute of Technology, Kanpur, where he was appointed as an Assistant Professor of Electrical Engineering and became a Professor in 1968. He went as a Visiting Assistant Professor of Electrical Engineering and Computer Science to the University of California, Berkeley, during 1965-66 where he reoriented his research and teaching to the fledging field of Computer Science. On his return in 1966 to IIT Kanpur, a Computer Science option in the Master's programme in the Department of Electrical Engineering was started which was the first academic programme in Computer Science in the country. He also initiated a doctoral programme in this area and a thriving school in Computer Science began at IIT, Kanpur. A dozen PhDs in Computer Science graduated in the next decade under his guidance. In 1982 he joined the Indian Institute of Science, Bangalore where he set up a National Supercomputing facility with a grant of Rs.500 million from the Government of India. During his career he guided 30 doctoral students in Computer Science (the highest number in Computer Science in India) and over 60 Masters Students and published over 70 papers in refereed journals.

As Computer Science was a new field, hardly any good affordable text books were available in India. He thus decided to write text books. Several generations of scientists and engineers learnt computer programming using the book on FORTRAN programming written by him in 1969. It was revised many times and is currently in its 50th printing. He followed up with books on computer design, information systems design, parallel

computers etc., writing a total of 23 books. He was a consultant to many IT industries notably TCS, ECIL, TELCO, SAIL R&D, HCL, BEL, and HP. He was a member of the Electronics Commission of the Government of India from 1979 to 1982 and under his leadership a new computer education programme called the MCA was designed and implemented which is a unique programme in India. He also started the first undergraduate Computer Science programme at IIT/Kanpur which was emulated by other IITs. He chaired the All India Board on Information Technology of the All India Council for Technical Education from 1993 to 2003. He was on the board of directors of several companies, notably CMC Ltd., Canara Bank Computer Services Ltd., and Encore Software Ltd. He was also on the board of IIIT, Trivandrum and IIIT Gwalior. He was IT advisor to IIM, Kozhikode from 2001 to 2009. From 1985 he has been a member of the Technical Advisory Panel of the Government of Karnataka overseeing its e-governance projects.

Prof.Rajaraman was awarded the Padma Bhushan (the third highest civilian award) by the President of India in 1990. He was elected a Fellow of the Indian National Science Academy in 1982 and served as a council member during 1986-88. He is a Fellow of the Indian Academy of Sciences, Bangalore, National Academy of Sciences, Allahabad, and Indian National Academy of Engineering, Computer Society of India, and the Institution of Electronics and Telecommunication Engineers. Among the many honours and prizes that he has received are Shanti Swarup Bhatnagar Prize (1976), Homi Bhabha Prize (1984), Indian Society of Technical Education award for excellence in Teaching (1988), Om Prakash Bhasin Prize (1992), Rustom Choksi Award (1993), S.H.Zaheer Medal (1998) and the Life Time Contributions award by the Indian National Academy of Engineering, Dataquest industry panel, Computer Society of India, and the Systems Society of India. In 2012 the Bengal Science and Engineering University awarded him an Honorary DSc(Engineering) degree.