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Nehru: The Unlikely Hero of India's Information Technology Revolution*

Dinesh C. Sharma

Abstract:

The Indian Information Technology – Business Process Outsourcing (IT-BPO) industry is estimated to be worth over US $ 85 billion in 2012, and its contribution to national GDP is pegged at over 6 percent. The Indian IT miracle, as it is widely known, did not unfold overnight. India, in fact, entered the era of modern computing more than 60 years ago with modest efforts made by two of the titans of Indian science - P C Mahalanobis and Homi Jehangir Bhabha – under the patronage of Nehru. The two scientists epitomized a very strong science-politics nexus, roots of which can be traced to a period much before independence. The two scientists played a leading role in shaping policies, institutions, and industries for computer hardware and software in the decades soon after independence. While patronizing scientists close to him to pursue their scientific goals, Nehru also blessed the private sector in the form of IBM which ultimately came to play a dominant role in the computing industry till it was forced to leave the country in 1977. In addition, Nehru nurtured Indian Institutes of Technology which, along with other modern engineering disciplines, marked the beginning of computer science education in India. The research centres created by scientists became the nucleus for development of engineering and programme writing skills. The overall result was the creation of an edifice on which was built a multi-billion industry in the decades that followed.

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The Indian IT-BPO industry (henceforth referred to as IT industry) represents a robust sector of the Indian economy. The sector has seen exponential growth in the past two decades. All through the 1990s, the growth rate was close to 50 per cent but it came down in 2000s. Unlike other sectors such as agriculture or manufacturing, the growth in this sector has been export-led. Most of the revenues earned are through export of software and related services in a variety of sectors. Yet the employment generation potential of the industry has been very high. In the initial years in 1980s, the industry could grow despite lack of physical infrastructure such as roads, ports, and airports which are prerequisites for traditional exports. This industry opened up a new avenue in the form of knowledge-based exports. So, availability of cheap and skilled manpower — and not physical infrastructure — was the key to its success in the initial phase of growth.

India's success in a highly competitive global technology and knowledge-based business is often described as a miracle and a result of certain turning points such as the Y2K or the Millennium Bug problem, which resulted in large amount of labour-intensive work outsourced to cheaper destinations like India. This is not the complete story. The success is neither a miracle nor a result of episodic events as Y2K or Euro conversion, but a cumulative result of an exercise which began soon after independence under the leadership of India's first Prime Minister Jawaharlal Nehru (1889-1964). The development of computer technology applications and industrial manufacturing of computers in the country was an offshoot of the larger alliance Nehru had with scientists.

The close links – personal and institutional – Nehru had with scientists were critical in giving due importance to development of science and technology infrastructure soon after India attained political freedom. It is these links that saw scientists play a decisive role in policy making relating to electronics and computers as well as in developing related industrial infrastructure in the public sector[1]. How these links developed prior to independence and flourished in the post-1947 period is an interesting part of science and technology development in India and impinges on evolution of the computing and information technology industry.

Science-politics Networks

The roots of the familiarity between Nehru and top scientists go back much before he became the first Prime Minister of free India. As

Chairman of the National Planning Committee (NPC), set up by the Indian National Congress in 1938, Nehru presided over formulation of a national development plan for India. In detailed history of India's atomic policies, Robert Anderson has investigated the roots of NPC formation. Science-politics networks were built almost a couple of decades prior to independence. Scientist Meghnath Saha and Congress leader Subhas Chandra Bose were contemporaries in college and were in England around the same time. Bose had invited Saha for a meeting of industry ministers organized by the Indian National Congress in 1938 where the idea of NPC was mooted. At this meeting, it was suggested that Sir M. Visveswaraya, an eminent civil engineer from the state of Mysore, be made the NPC President but Saha suggested that an important member of the Congress party, such as Nehru, should head NPC so that it is taken seriously and is not considered a mere academic exercise.[2]

The forum of NPC provided an opportunity to Nehru to develop contacts with several leading scientists of the period. Prasanta Chandra Mahalanobis, who had founded Indian Statistical Institute (ISI) in Calcutta in 1932, was among them. Nehru visited ISI in 1940 and requested Mahalanobis to prepare statistical commentary on reports of NPC. This was the beginning of a long association between the two that resulted in Mahalanobis playing a legendary role in Indian planning for the next four decades. Saha was also a member of the Board of Scientific and Industrial Research (BSIR) set up by the empire mainly to boost industrial research and to establish links between scientists and industry. The Board was headed by Shanti Swarup Bhatnagar, who maintained close links with key men in the government such as Sir Ardeshir Dalal as well as industrial houses like the Tatas and the Birlas. All this helped him foster the idea of setting up a chain of laboratories in key areas for industrial research under the aegis of the Council of Scientific and Industrial Research (CSIR). Under CSIR was set up an Atomic Energy Committee in 1945 to explore availability of raw materials required for generating nuclear energy and 'suggest ways and means of harnessing the materials for production of nuclear energy'. Homi Jehangir Bhabha was Chairman of this committee. Soon the committee was branched off as Board on Research in Atomic Energy with an objective to 'plan and implement all atomic research and development in the country'.

The informal links Nehru established with scientists through the NPC got converted into institutional networks after independence. In an unusual step, Nehru created a Central Statistical Unit and appointed

Mahalanobis as Honorary Statistical Advisor to the Union Cabinet in February 1949. Two years later, the Central Statistical Orgnisation was set up to coordinate statistical activities of all government departments. Subsequently, a Department of Statistics was created as a new wing of the central government. ISI was given the status of National Statistical and Computational Laboratory in 1959 through a special legislation passed in the Parliament. This empowered ISI to award degrees in statistics. Similarly, Bhatnagar could expand the CSIR chain of national labs at great speed with patronage from Nehru. The Board on Research in Atomic Energy was replaced by an independent Atomic Energy Commission (AEC) in April 1948, through the Atomic Energy Act passed in the Constituent Assembly. Subsequently, a separate Department of Atomic Energy (DAE) was set up by the government in 1954 and AEC brought under its purview. Nehru appointed Bhabha as head of both these new government bodies – DAE and AEC. Bhabha, Mahalanobis, and Bhatnagar thus formed the great *troika* of Indian science in the Nehru era, controlling a large chunk of scientific research activity in the newly independent nation.

Nehru saw science and technology as key inputs for development of independent India. The Scientific Policy Resolution he presented in the Lok Sabha on 13 March 1958, summarized his vision. It noted that 'Science and technology can make 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, a 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'.[3] In this grand vision of science and national development, introduction of computers in India fitted well, with two members of the triumvirate – Bhabha and Mahalanobis – playing pivotal role in computer technology development and applications.

The idea of self reliance in science and technology, in Nehru's vision, did not exclude technical help from technologically advanced countries. Science, for him, was international and had to be used for the benefit of humanity as a whole. He wanted India to develop capability in both industrial production and technology.[4] During his first trip to the US in 1949, Nehru was impressed with its technological growth and took keen interest in emerging areas of science and engineering. In this trip, he met several technical and engineering leaders and had begun exploring

how they could help India in areas like hydro-electric power generation. He was so impressed with Tennessee Valley Authority that he wanted the Damodar Valley Project to be modelled after it.

Nehru gave scientists top positions in the government and decision making. Scientists were made secretaries of the respective departments and ministries they headed, at par with civil servants. The treatment, however, was limited to scientists close to him. The science-politics alliance did not automatically extend to all top scientists. India's only Nobel Laureate C. V. Raman had no place in the new set up, nor did Saha who was active in NPC and close to Nehru in pre-independence era. Saha became a bitter critic of Nehru, fought election against the Congress party and attacked the Prime Minister on several key issues in the Parliament. In particular, he was critical of Nehru's support to the atomic energy and patronage of Bhabha.

Despite so much support to science and enunciation of a scientific policy resolution, the country did not have a formal structure for scientific policy formulation. This resulted in benign neglect of agriculture research, though the Indian Council of Agriculture Research (ICAR) was the oldest research councils functioning in India. Unlike organisations headed by the triumvirate, ICAR was not an autonomous body but worked as an appendage office of the Agriculture Ministry. The first formal structure for scientific matters was in the form of the Scientific Advisory Committee to the Cabinet set up in 1956, after Bhatnagar's death. It was Lal Bahadur Shastri in 1965 who accorded agriculture research a priority, appointed a scientist to head ICAR and gave the Indian Agriculture Research Institute (IARI) the status of a national institute. B. P. Pal, who headed ICAR, himself commented that had Nehru been directly associated with ICAR, just like CSIR and DAE, agriculture science would have advanced a great deal.

Top scientists close to Nehru were great institution builders. The strong science-politics nexus in the Nehru era led to development of large scientific clusters around scientists close to the top political leadership. The high status given by Nehru to scientists in the government helped them derive their administrative power and enjoy a clout within the government, while pursuing their respective research goals. CSIR developed a great deal with Bhatnagar at the helm. The ISI founded by Mahalanobis was accorded the status of a national institution and the CSO was set up within the government. The Tata Institute of Fundamental Research (TIFR) set by Bhabha too became an institution

of national importance, and a nucleus for development of atomic energy in the country. The Atomic Energy Establishment (renamed Bhabha Atomic Research Centre after Bhabha's death) became a hub of atomic energy related research.

Just as he encouraged building dams and steel plants, Nehru encouraged new technology and computers. Computing was considered strategic since it was just developing in the West. American firm, International Business Machines (IBM) was present in India since 1951 in Calcutta, where it had supplied Unit Record Machines to ISI. Arthur Watson, Chairman of IBM World Trade Corporation visited India twice in the 1950s. During his visit to the US in December 1956, Nehru is reported to have visited IBM plant and invited the company to set up a factory in India.[5] Watson met Nehru when he visited India and signed an agreement to set up a manufacturing unit in 1959. It was the beginning of the data processing industry in the country. This would make India the eighth country in the world to have an IBM manufacturing plant.

Nehru was acutely aware of the need for India to acquire some computing power in view of the large planning and statistical surveys being executed under the leadership of Mahalanobis. Most of the data processing machines had to be imported at great cost and huge rental charges had to be paid for them as ownership was not allowed. ISI activities were under constant public gaze because of the high profile nature of relationship between the prime minister and the top scientists. Often questions were asked about the functioning of ISI in the parliament. The issue of the institute using foreign exchange for renting of analog and electronic computing equipment was also raised while the Parliament was debating the bill related to granting national institute status to ISI in December 1959. ISI was then paying rental of about Rupees 8,00,000 to Rupees 9,00,000 to British and American companies. Nehru had to defend the action himself, saying 'these complicated sets cannot be purchased' and that this [giving machines on rent] was the practice in other countries also.[6]

Nehru was fully acquainted about the role of tabulating machines and computers and also of the fact that such equipment was treated somewhat strategic by Western companies. This perhaps prompted him to ask IBM to set up local manufacturing in India when Watson met him in New Delhi the same year. Thus began India's relationship with a leading American multinational corporation working in a high technology area. In the initial days of IBM in India, Nehru nurtured the company.

He came to Ashoka Hotel in March/April 1961 when IBM held a training programme for its first batch of Indian recruits.[7]He gave away certificates to the trainees.

Computer Development Work at ISI

The work related to development of data processing and computing devices at ISI was born out of sheer necessity. In the wake of the Bengal famine, the Government of Bengal asked Mahalanobis to conduct a similar survey for paddy yields. For this work, Mahalanobis needed computing machines. Since imports of tabulators and such equipment was difficult after the war, Mahalanobis decided to set up a facility to develop and fabricate computing machines locally. He established a non-profit body called Indian Calculating Machine and Scientific Instrument Research Society, specifically for development of calculators and scientific instruments in September 1943. This was the first attempt in India to design and fabricate calculating machines and other related scientific instruments. ISI already had a workshop for repair and maintenance of calculators. In 1950, Mahalanobis consolidated all these efforts under the umbrella of an Electronic Computer Laboratory at ISI.

Young scientists hired by Mahalanobis designed and fabricated India's first 'analogue electronic computer' in 1953, mostly using recycled components and some fabricated at the institute's workshops. They published a scientific paper on this feat in the Review of Scientific Instruments in May 1955.[8] The machine was shown to Nehru in December 1953. It took a long time for solving linear equations because all operations were manual. The computer was reported to be functional till 1959 at ISI. While working on indigenous machines, Mahalanobis was conscious of the fact that these were not standard machines and much bigger computers were needed for operational work of ISI. That's why while nurturing design and engineering teams at ISI, he kept himself abreast of latest developments in digital computing and wanted his fellow scientists to acquire new skills in computing. He visited the Harvard Mathematical Laboratory to get first hand information on developments in electronic computing in 1950 and met John von Neumann and Howard H Aiken.[9]

Later Mahalanobis acquired a large computer designed by Andrew Donald Booth, a pioneer in electronic computing at Birkbeck College. Booth had developed an Automatic Relay Computer and an All Purpose Electronic Computer (APEC) during 1947-49.[10] Commercial variants

of this machine were eventually sold by British Tabulating Machine (BTM under the name of Hollerith Electronic Computer- HEC. ISI acquired one such machine with the idea of exposing ISI engineers to functioning of a modern computer so that they can develop similar and bigger systems on their own.[11] The cost of this machine was about Rupees 5,00,000. The machine BTM, custom built for ISI, was called HEC-2M. Only seven or eight such machines were sold globally, and the one at ISI was Asia's first. Mahalanobis later got another big computer, Ural, from the Soviet Union using the close ties he enjoyed with the Soviet Science Academy. Ural was described as 'fully automatic electronic computer capable of solving complex mathematical problems with great speed and accuracy'.[12] ISI also developed a second generation, transistor-based computer in collaboration with the Jadavapur University. The machine called ISIJU-1, however, did not seem to be a successful venture.[13]

Early Work at TIFR

While Mahalanobis took to data processing and computer development activity to pursue his goals in statistics, Bhabha did so for his goal of building an indigenous nuclear reactor and pursue nuclear research. He also put together a team of young engineers to develop an indigenous digital computer early on. This resulted in design and fabrication of the TIFRAC or TIFR Automatic Calculator, which was ready in 1959 but formally declared functional by Nehru in January 1962 when he came to inaugurate the new building of TIFR at Colaba. Though not a technological breakthrough, TIFRAC helped Indian scientists gain capability in various fields of computer design, fabrication, testing, operation, maintenance and programming. A hard core of specialists had grown to maturity who could tackle with confidence the logical, circuit, system, and engineering design of a variety of digital equipments.[14] Since it was a custom-made machine, both operating programme and applications had to be written for using it. This led to development of initial software programming capabilities.[15]

Like Mahalanobis, Bhabha too realized that India needed standard computers for operational work. This led to shift from non-standard, experimental machines like TIFRAC and ISIJU to standard machines (IBM 1401 at ISI and CDC 3600 at TIFR). The CDC system helped Indians gain experience in handling such a large system right from its fabrication, installation, and testing to solving complex problems. Specific capabilities were developed in hardware and software maintenance, software programme writing, hardware troubleshooting,

peripherals and components fabrication, and overall system management. Thus early capabilities in hardware design, software programming, maintenance and training were developed in late 1950s and early of 1960s.

In addition to their own areas of research, of which computer development activity was a part, both scientist-confidantes of Nehru were involved in policy making as well. Mahalanobis was involved in development planning, while Bhabha got drawn into science and technology planning. After the Indo-China war in 1962, Bhabha was involved in policy decisions at Delhi, particularly those relating to making India self-reliant in manufacture of different types of equipments.[16] The war was a wake up call for the government. It realized the importance of an indigenous electronics industry after the country lost the war. The armed forces experienced acute shortage of electronic components during the war. A specific instance was the short supply faced for Transit-Receive switches used in imported radars. An SOS was sent to Bhabha at TIFR and the microwave engineering group at the institute delivered these switches to the forces.[17] It was difficult to procure strategic electronics in open markets, while TIFR and AEE had developed some level of expertise in fabrication of electronic instruments for research.

Policy planners in Delhi thought that India should initiate its own efforts in the emerging area of electronics. Cabinet secretary, S. S. Khera, who was a member of the Atomic Energy Commission (AEC), suggested that DAE should set up a committee to take a comprehensive look at India's electronic requirements, including computers, under the chairmanship of Bhabha. The objective was to assess the country's requirement of electronic equipment in various sectors and identify existing and potential sources of supply. Most important, the committee was asked to recommend measures for 'planned development of electronics, so that the country as a whole may become self-sufficient in this field in the shortest possible time'. The resolution setting up the committee said 'electronics is the nervous system of modern technology and has assumed an important role in monitoring and controlling production process in engineering, chemical and metallurgical industries. It is vital for atomic energy, communication, and defence'.[18]

The Bhabha committee report proved to be a landmark for electronics and computer development in the country. The report argued that electronics industry can contribute to national income and generate jobs, with much less investments than steel or chemical industries. The

small size of the industry, it said, could be turned into an asset if the early stages in the development of the industry as seen in other countries was bypassed and the industry was based on latest ideas and techniques. Essentially, what Bhabha advocated was that India should avoid 'step by step' development of electronics industry as seen in developed countries and instead, should leapfrog. The government accepted all the recommendations and this eventually resulted in setting up of a separate wing in the government — Department of Electronics (DoE) and the Electronics Commission (EC). The electronics wing of AEE was spun off into a separate PSU – Electronics Corporation of India Limited (ECIL) in Hyderabad. A number of institutions such as National Informatics Centre, Computer Maintenance Corporation and National Centre for Software Development and Computing Techniques were promoted by DoE in the 1970s.

Technical Education at IITs

Developing modern higher education infrastructure was necessary for India to achieve goals in scientific research and development. As a stop gap arrangement, the government started giving fellowships to students for pursuing post graduation and doctoral studies abroad. A blueprint for India's foray into world-class engineering and technical education was ready when India gained independence in August 1947 in the form of the interim report by the Nalini Ranjan Sarkar committee on higher education submitted to the Viceroy in 1946. The first institute envisaged in the report – initially called 'Eastern Higher Technical Institute' came up in the Eastern region at Hijli near Kharagpur only after the independence. At the time of independence, India had some of the finest institutions for scientific research – Indian Institute of Science at Bangalore, TIFR at Bombay, and ISI in Calcutta. But the country lagged behind in engineering education. In 1946, the country had 46 engineering colleges with a total intake capacity of 2,500 and there was no post graduate education in engineering.[19] So, Nehru pursued Sarkar's blueprint in right earnest. The planning work for the institute started in May 1950 and first batch of undergraduate students was admitted in July 1951. In 1958, the second IIT came up in Bombay, followed by one at Madras in 1959, and Kanpur in 1960. The College of Engineering, set up in Delhi in 1961, was also renamed as IIT.

Nehru wished Indian engineering schools to be among the best engineering and technology centres in the world, so he roped in some of the leading higher education institutes of the West as partners to developing different IITs. External technical and financial help was also

inevitable due to the fact that national resources were inadequate to set up all such centres. Help from different countries would have also meant a diversified engineering and technical education system. For IIT Bombay, United Nations Educational, Scientific and Cultural Organisation (UNESCO) agreed to make available equipment and technical expertise from the Soviet Union. In addition, further financial aid was provided through a bilateral agreement between India and USSR. During his visit to West Germany in 1956, Nehru was offered help to set up a higher technological institute in India, which he readily accepted. The agreement provided for setting up an Indian Institute of Technology at Madras with German assistance in the form of services of professors and foremen, training facilities for Indian faculty and supply of equipment.[20]

Nehru was keen to involve Massachusetts Institute of Technology (MIT) in development of IITs, as envisaged in the Sarkar report. The first two institutes – at Kharagpur and Bombay – had international involvement but did not benefit directly from the MIT experience. In 1958, the International Cooperative Alliance requested MIT to send a team to India and help the government prepare a blueprint for an IIT at Kanpur. Apparently, MIT refused citing a shortage of manpower. So, instead of MIT, a delegation of six eminent educators from the American Society for Engineering Education was sent to India in 1958. After studying the Indian system and proposals, this panel gave a voluminous report to the Indian government. Bowing to pressure from Indian authorities, MIT deputed a three-member team led by mechanical engineer Norman C. Dahl, to further study how MIT could help IIT Kanpur grow. The visit was sponsored by the Ford Foundation. This team found that the status of engineering education in India was similar to American institutes.[21] MIT finally agreed to lead a consortium of American universities to help set up the Kanpur institute. After a few more visits from both sides, a formal agreement was signed by the United States Agency for International Development and the Indian government. Thus was born the Kanpur Indo-American Project or KIAP in August 1961.

IITs have played a pioneering role in the development of computer science education in India. The trigger for this at IITK was the KIAP, under which the institute acquired India's first IBM 1620 computer in 1963 and IBM 7044 in 1966. These two computers formed the core of the Computer Centre at the institute, which became the training ground for the first generation of Indian computer programmers and computer science graduates. The centre benefited not just undergraduates,

graduates and faculty of the institute but scores of people from research, academia, and industry all over the country. IITK also initiated engineering education in computer science. Many like N. R. Narayana Murthy and Prabhu Goel cut their teeth into programming in Kanpur and all top companies then such as TCS, ORG, and DCM hired their first lot of programmers from here. Computer science activity started at IIT Bombay in 1967 with a second generation computer it got from the Soviet Union, Minsk II. IITM acquired a digital computer – IBM 370 –from Germany much later which was used to develop software for ECIL. IITs, thus, played a key role in preparing skilled manpower in hardware design as well as programming.

Gains of the Nehru era

A full-fledged IT industry did not exist in the Nehru era. But efforts made by Bhabha and Mahalanobis under the political patronage of Nehru were significant in many ways. They laid the foundation of a future industry. The first generation computers which scientists build helped Indians gain capabilities in design, fabrication, testing, operation, and maintenance. When large systems were imported, Indians could gain experience in handling large systems right from the stage of fabrication. Knowledge transfer took place through training, flow of documents, manuals, and visiting engineers. This knowledge was further disseminated by TIFR, ISI, and IIT Kanpur to larger community of academics and researchers as well as industry users. For instance, 150 institutions used CDC machine at TIFR in five years. This helped spread computer consciousness beyond research institutes and helped develop initial software programming skills. Since all proprietary machines needed custom-made software, users were forced to write their own software. Foreign firms like IBM, CDC and ICL hired local engineers to write programmes and programming manuals. All this meant that the first generation of Indian programmers was born in the decade of 1960.

At the institutional level, centres created by the scientists became fountainhead of electronics and computer development giving rise to computer applications in government and private sector and industrial scale manufacturing of IT products. When commercial IT industry took roots in 1970s after the exit of IBM, India already had a vast policy making apparatus in electronics and computers; a large base of computers in research, development, and design; users in academia, research, and industry; a number of mainframe installations; and above all, a pool of trained manpower in hardware, software, applications, and maintenance.

Endnotes :

[1] Dinesh C. Sharma, *The Long Revolution* (India: HarperCollins Publishers, 2009), pp. 41-45.

[2] Robert S. Anderson, *Nucleus and Nation* (University of Chicago Press, 2011), pp. 83-85.

[3] Baldev Singh (ed.), *Jawaharlal Nehru on Science and Society* (New Delhi: Nehru Memorial Museum and Library, 1989), p. 158.

[4] Ibid.

[5] Sunil Agarwal, '30 years of the Indian computer industry', *Dataquest*, Jan. 1985, p. 43.

[6] Nehru participating in the discussion on the bill to grant status of national importance to ISI in Lok Sabha on December 14, 1959. Baldev Singh (ed.) , *Jawaharlal Nehru on Science and Society* (New Delhi: Nehru Memorial Museum and Library, 1989) p. 209.

[7] Personal Communication with former executives of IBM India.

[8] 'Electrical Analog Computing Machine for Solving Linear Equations and Related Problems', *The Review of Scientific Instruments*, May 1955, pp. 453-457.

[9] D. Dutta - Majumder, 'Thoughts on Emergence of IT Activities in India' - in *Computer Education in India: Past, Present and Future*; Utpal Banerjee (ed.), Concept Publishing Company (New Delhi, 1996), p 4.

[10] 'The work of Professor Andrew D. Booth' , School of Computer Science and Information Systems, Birkbeck College, University of London <http://www.dcs.bbk.ac.uk/about/history/booth.html>, accessed April 15, 2007.

[11] Ashok Rudra, *Prasanta Chandra Mahalanobis: a biography* (Oxford University Press, 1996), p. 277.

[12] 'Soviet Electronic Computer – URAL' – in *Samvadadhvam*, Vol. 2 No. 4, July-Sep 1958, ISI pp. 22-23.

[13] Dinesh C Sharma, *The Long Revolution (*India: HarperCollins Publishers, 2009), p. 13.

[14] R Narasimhan 'Men, machines and ideas: an autobiographical essay', *Current Science*, Vol. 76, No 3, February 1999, p. 449.

[15] 'Work in Computer sciences and technology: A summary and a projection' , D-2004-01355- 2[8], TIFR Archives.

[16] Transcript of unpublished interview with A. S. Rao, by S. P. K. Gupta, 1973.

[17] B. V. Srikantan, 'Sixty years of the Tata Institute of Fundamental Research 1945-2005: The role of young men in creation and development of this institute', *Current Science*, 90/5, 10 March (2006), p. 1022.

[18] *Electronics in India: Report of the Electronics Committee*, February 1966, p. 4.

[19] Amitabha Ghosh, 'Evolution of the IIT System and Excellence in Higher Education' in *Reflections*, Vol. 8, Number 1, April 2007, p. 15.

[20] 'History of IIT, Madras', IITM Website, <www.iitm.ac.in>, accessed Jan. 29, 2007.

[21] Stuart W Leslie, 'Exporting MIT: Science, Technology and Nation-Building in India and Iran', *OSIRIS*, University of Chicago Press, p. 115.