PUNE INTERNATIONAL CENTRE

Outstanding Indian Achievers and Their Quest for an Atmanirbhar Bharat

February 2024

By
Major General Nitin Gadkari (Retd)

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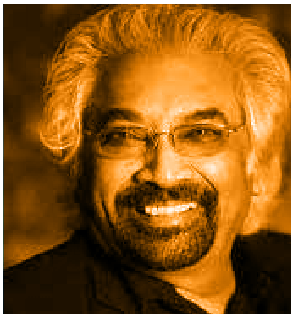
ABBREVIATIONS

S. No	Abbreviation	Full Form
1	APSOH	Advanced Panoramic Sonar Hull Mounted
2	AC	Air-Condition
3	AEC	Atomic Energy Commission
4	ASW	Anti-Submarine Warfare
5	AVSM	Ati Vishisht Seva Medal
6	BARC	Bhabha Atomic Research Centre
7	BDL	Bharat Dynamics Limited
8	BEL	Bharat Electronics Limited
9	B Tech	Bachelor of Technology
10	BSNL	Bharat Sanchar Nigam Limited
11	CAT	Centre for Advanced Technologies
12	CAIR	Centre for Artificial Intelligence & Robotics
13	CCS	Cabinet Committee on Security
14	Cdr	Commander
15	C-DAC	Centre for Development of Advanced Computing
16	C-DOT	Centre for Development of Telematics
17	CIA	Central Intelligence Agency
18	CRL	Central Research Laboratory
19	CONPAR	Conference for Parallel Computing
20	Cmde	Commodore
21	DAP	Defence Acquisition Process
22	DEW	Direct Energy Weapons
23	DODN	Digital Own Doppler Nullification
24	DPP	Defence Procurement Procedure
25	Dr	Doctor
26	DRDO	Defence Research & Development Organisation
27	ECI	Electronic Commission of India
28	ER&DC	Electronic Research & Development Centre
29	FLOPS	Floating Point Operations Per Second
30	GDL	Gas Dynamic Lasers
31	GOI	Government of India
32	GTE	General Telephone & Electronics
33	HPL	High-Powered Laser
34	HPC	High-Power Computing
35	HQ	Headquarters
36	ICBM	Inter-Continental Ballistic Missiles
37	IC	Integrated Chips
38	ICT	Integrated Computer Technologies
39	IIT	Indian Institute of Technology/Illinois Institute of Technology
40	IEEE	Institute of Electrical & Electronics Engineers

S. No	Abbreviation	Full Form
41	INR	Indian Rupee
42	INS	Indian Naval Ship
43	IOS	I Phone Operating System
44	IRDE	Instruments Research & Development Establishment
45	ISD	International Standard Dialling
46	IT	Information Technology
47	KELTRON	Kerala State Electronics Development Corporation
48	kW	Kilowatts
49	LASTEC	Laser Science & Technology Centre
50	LCA	Light Combat Aircraft
51	Lt	Lieutenant
52	MAD	Mutual Assured Destruction
53	MIMO	Multiple Inputs Multiple Outputs
54	MOS	Minister of State
55	MOD	Ministry of Defence
56	MNC	Multinational Corporation
57	M Tech	Master in Technology
58	MSU	Maharaja Sayajirao University
59	NDA	National Defence Academy/National Democratic Alliance
60	NF	Notch Filtering
61	NPOL	Naval Physical Oceanography Lab
62	NM	Nautical Mile
63	OSD	Officer on Special Duty
64	PhD	Doctor of Philosophy
65	PI	Ping to Ping
66	PM	Prime Minister
67	PNS	Pakistan Naval Submarine
68	Prof.	Professor
69	RAX	Rural Automatic Exchange
70	R&D	Research & Development
71	ROI	Return on Investment
72	SDI	Strategic Defence Initiative
73	STD	Standard Trunk Dialling
74	SSPL	Solid State Physics Laboratory
75	TIFR	Tata Institute of Fundamental Research
76	UK	United Kingdom
77	US	United States
78	USSR	Union of Socialist Soviet Republics
79	USP	Unique Selling Point
80	VCNS	Vice Chief of Naval Staff
81	VRCE	Visvesvaraya College of Engineering
82	VSM	Vishisht Seva Medal

Outstanding Indian Achievers and Their Quest for an Atmanirbhar Bharat



Sam Pitroda

Prof. Amitav Mallik

Cmde Arogyaswami Paulraj

Dr. Vijay Bhatkar

Introduction

The quest to be self-dependent is a universal aspiration, transcending the boundaries of humans, organisations and nation-states. Even Adam Smith recognised the need for nations to be independent while being dependent when he propagated the theory of 'Absolute Advantage'. India's journey to self-sufficiency is also a long one. All along India's independent history, governments have supported domestic productions. However, skewed in its implementation, the Licence Raj era aimed to encourage domestic industry. Under the leadership of Prime Minister Shri Narendra Modi, the NDA (National Democratic Alliance) government has given a new impetus to the 'Make in India' initiative. The government has opened the economy to encourage competition and a level playing field for domestic players. The good part of the government initiative is not to curb competition. Quality will rule, provided it is affordable. But does mere sloganeering help nations come out of the slumber deep-rooted in the system? What does it take to become 'Atmanirbhar' (Self-Reliant and Self-Dependent)? These questions keep haunting policymakers, Industrialists, and entrepreneurs alike.

A simplistic thought on 'Atmanirbharta' could suggest the ability to produce all required goods or services for an entity at home without assistance from any foreign source. Is that desirable? In today's world, where nations' economies intertwine, is it prudent to produce every component in one's own country for being Atmanirbhar? Most economists would disagree. Another thought suggests using resources to the extent possible through indigenous technology, leadership, innovation, and finance to produce goods and create a demand for domestic consumption. The second thought seems more realistic, as it has the five pillars of Atmanirbharta enunciated by Shri Narendra Modi, the Indian Prime Minister. Relating it to smaller entities like corporations or individuals, the above has five essential ingredients: Need, Leadership, Innovation, Finance, and Indigenous Resources. This paper attempts to analyse these essential ingredients and pre-requisites needed to become Atmanirbhar by examining the outstanding achievements of four Indians: Sam Pitroda, Prof. Amitav Mallik, Cmde Arogyaswami Paulraj, and Dr Vijay Bhatkar. All four used cutting-edge technology to make high-value products, significantly impacting India's standing in the world and contributing in considerable measure to public service and national security. All four achievements would stand the scrutiny of a technology audit to qualify as the next-generation technology designs when adopted. All four were borne out of the need for service to the nation. Leading these four case studies are four brilliant Indians who competed against the best in the world to come out on top despite the paucity of resources, sanction regimes, MNC (Multinational Corporation) pressures, and a sceptical domestic environment. The personalities involved are shining lights who are beacons for the new generation. 'If they could do it then, we can do it now' is the message they convey through their achievements.

Aim

The paper aims to understand, through the works of four eminent Indians, their success stories in their respective spheres, using cutting-edge technology harnessed through indigenous resources. Take lessons from their experiences, for the policymakers, industrialists, and the entrepreneurs, to help India progress towards being 'Atmanirbhar'.

Scope

The scope of the paper is limited to examining one project per personality. Each of these individuals has done work beyond the project chosen for elucidation. However, their other achievements do not form part of the paper. The life of each achiever is worth many books, but their life stories do not find part of the narrative for the sake of brevity of this paper.

The paper does not delve into the details of the scientific explanations of the innovations/work done. The narrative is kept simple for everybody's comprehension.

Outline of the Paper

The paper is in three parts. The first part deals with the introduction and the description of the work done by each of the four personalities involved. Part two consists of the lessons learnt from these cases. Part three gives recommendations for policymakers and entrepreneurs to help them pursue the path of 'Atmanirbharta'.

PART 1

Introduction

Technology drives human progress. From its nascent form in the 19th century, when it emerged and fuelled the industrial revolution, to modern-day Artificial Intelligence and beyond. It is technology that drives change. India started on the slow side of the technological revolution, but in the last few decades after Independence, it has taken giant strides in some areas, in competing with the best in the world. India's space programme and the success of Chandrayaan-3 indicate the progress. We were slow in adapting and innovating. Many factors contributed to it. Being a young independent nation robbed of its riches by the past masters, multiple challenges such as cultural integration, illiteracy, health, and poverty alleviation were a few amongst the most important reasons.

The innovative spirit was dormant, but not missing. It surfaced when two bright Indians got a chance to prove themselves. Dr Homi Bhabha and Dr Vikram Sarabhai, two scientists, gave India the hope of harnessing nuclear energy and using rockets in space. Through their contributions, we are a nuclear weapons power in our own right and have a successful space programme. Such examples have given Indians the desire to excel in the world.

Through the maze of development, which was slow in the initial years after India's independence, there were pockets of excellence which were brewing and waiting to surface in every decade, after the two Indian scientists named above showed the way. Other men of Science wanted to leave their stamp on innovations and discoveries. They desired to harness technology to bring progress to this country. They worked through sanctions and control regimes to bring the technological revolution to India. The paper examines four case studies and the personalities associated. These people pioneered the achievements in their respective fields through their dogged determination and a deep desire to do something meaningful for their nation. Moreover, in doing so, trail blaze for the next generation to lay a strong foundation for an 'Atmanirbhar Bharat'.

The four case studies under examination are C-DOT (Centre for Development of Telematics) by Sam Pitroda, HPL-DEW (High-Powered Laser and Direct Energy Weapons) by Prof. Amitav Mallik, APSOH (Advanced Panoramic Sonar Hull-mounted) by Cmde (Commodore) Arogyaswami Paulraj, and the fourth, Param 8000 Supercomputer by Dr Vijay Bhatkar. All these four projects dealt with cutting-edge technology. Two pioneered a new trend, and the other two demonstrated India's capability to come up with an indigenous answer to the best in the world. Sam Pitroda's C-DOT was the first to use digital Switches of the order of 128 lines. Manufacturing them required mending the existing technology of the West, which dealt with exchanges of large sizes. These needed tweaking to suit Indian conditions of heat and humidity. The success of small exchanges started a telecom revolution in India. Few third-world countries adopted it too. Prof. Amitav Mallik's indigenous production of High-Powered Laser and Direct Energy Weapons is India's equivalent of US Star Wars. Indigenous production of high-powered lasers is a technological wonder for any developing country. The requirement of cutting-edge technology in producing the laser beam through the related components is not available in the open market as they come under a sanction regime. Moreover, it was a top-secret programme in countries which possessed them. Cmde Arogyaswami Paulraj designed the most advanced Sonar available to any navy in the world. It beat the best that France, the UK (United Kingdom), Germany, or the Soviet Union had to offer. The fourth case study is Dr Vijay Bhatkar's quest to give India its first supercomputer. This innovation was in retaliation to the US's humiliating rejection of Indian Prime Minister Rajiv Gandhi's request to give India a Cray Supercomputer for its weather forecasting needs. The Param computer was so good that it came second in the Zurich supercomputer fair, next to the Cray X-MP. Next year, after a demonstration in Washington, the Wall Street Journal came out with a report: "Denied supercomputers, angry India does it". All these powerful stories are waiting to be told for others to learn from them. The paper attempts to narrate these case studies and examines the lessons that could be derived for policy-making and future entrepreneurs. The sequence of the case studies is as follows:

- C-DOT by Sam Pitroda
- HPL & DEW by Professor Amitav Mallik
- APSOH by Cmde Arogyaswami Paulraj
- PARAM by Dr Vijay Bhatkar

Sam Pitroda: India's Telecom Revolution

Sam Pitroda's name would figure very high on any list which celebrates people who helped India's journey towards being self-reliant and self-sufficient: 'Atmanirbhar'. Sam (as he is popularly known) after his initial studies in Gujarat, travelled to the US (United States) to seek higher education. He majored in Electrical engineering from the Illinois Institute of Technology (IIT). After his post-graduation, he worked for major telecom companies in the US, such as the GTE (General Telephone & Electronics), Bell Telephones, Rockwell International, & Wescom Inc. With such vast experience of working in the field of telecommunications, he was best placed to understand the technological and human resources that are required to set up a telecommunication network for big organisations. In these companies, he designed digitised Switches and electronic equipment for telecommunication networks. He was highly sought after for his expertise in his field. Yet, he desired to do something different. Something for his country: India. He wanted to overhaul the primitive telephone network connectivity in the country. His heart was set on improving telephone accessibility in India.

His first visit to India in 1980 convinced him of the dismal state of communications in the country. He could not put a call to his wife in the US informing her of his safe arrival. The next day he witnessed a funeral on the road outside his hotel. It was no ordinary funeral. It was a funeral of dead phones. Telephone in India in those days was a privileged commodity, and only people with clout or money had access to it. If this was the state in the urban part of the country, he was convinced the telephone services were non-existent in the villages, where 70% of India's population resided. His telecom revolution thus started from the villages. He called it the C-DOT (Centre for Telematics Development) revolution.

C-DOT

During his days when Sam Pitroda was working for Wescom in Chicago, he attended the 'India Forum' meets. They talked about how to change things in India for the better. Sam gave a talk on the rudimentary state of Telecommunications in India. He believed that telephone revolution in India has to start from the villages to modernise India. The way to go about it was through small exchanges in rural India. It was an idea which struck a chord with Mr Rajiv Gandhi. He impressed upon his mother, Mrs Indira Gandhi, the then Prime Minister of India, to listen to Sam Pitroda because he had a good idea. The main goal of C-DOT was to develop accessibility and rural communication, focusing on self-reliance. In 1980, in a presentation to the Prime Minister, he proposed modernising telecom through indigenisation and local production. It appealed to Mrs Gandhi. At the end of the presentation, she smiled and said, "Good".

After getting a nod from the Prime Minister, the government opened its doors for Sam Pitroda to implement his plan. It was an ambitious plan. India was devoid of any telecom infrastructure or production facilities for digital equipment. Sam had to build his dream of 'Connecting India' from scratch. In Sam's words, "We needed to create a core research and development group that would design uniform equipment meeting uniform standards, especially exchanges, focusing on the countryside first, and then the cities. The core group would require government support but must be independent of the existing bureaucracy. Building indigenous equipment would require us to establish local manufacturing sources. In the process, we could modernise our phone systems, provide access to the bulk of our population, and develop our technology, entrepreneurs, human resource and industrial base". (page 106/107: Dreaming Big)

The above indicates the gravity of the odds against which Sam had decided to take up the challenges of 'Connecting India'. Apart from the technological challenge of producing small digitised exchanges for rural India, the bureaucratic hurdle was more difficult to get past. The telecom ministry, the finance ministry, and the Industrial Production ministry were all involved and had to be brought on board if the project was to take off from the ground. The vested interests of the existent telephone ministry were the most significant threat. Thus, manoeuvring around the bureaucratic maze of the national capital posed a greater challenge to Sam. That he was able to surmount it and forge ahead is a tribute to his human resource acumen and his honest approach towards his goal of connecting India. He also admits in his book that without the support of Mr Rajiv Gandhi, at first as a son of the Prime Minister and then as a Prime Minister himself, he would have failed in his mission. His visionary leadership laid the foundation for C-DOT. It received formal cabinet approval in April 1984 with a budget of 36 million US dollars and a three years' time frame for completion.

His first task was to establish an organisation. He created C-DOT; it was raised as an organisation funded by the government, yet out of bureaucratic control to enjoy autonomy, flexibility and freedom of action. Its organisational structure was horizontal. Sam Pitroda had no official designation in C-DOT. He was a mentor. It had an Executive Director: Dr Meemamsi and under him two directors: Dr Meemamsi officiated as Head of Telecommunications Research Institute, and Dr Pitke from Tata Institute of Fundamental Research (TIFR). There were three managers under the directors. One each for Software development, System Development and Hardware Development. The next important task was hiring of the engineers. Most candidates came through advertisements. The board screened the potential candidates for their technical prowess and then were vetted by Sam Pitroda for their aptitude. The teams were divided into two parts. The first was with Dr Meemamsi, operating out of Delhi, looking after the software and system development. The second was for hardware design and development under Dr Pitke, based in Bangalore. Sam says, "Training our engineers was anything but a simple process.

They were smart – you could see the intelligence sparkling in their eyes. They had all been to top-notch schools. Their enthusiasm was off the charts. But they were so young. Most of them had thought extremely little, if at all, about telephone switching". (page 121: Dreaming Big)

The intermediate period of design and development was challenging for handling technological and human resource challenges. Sam Pitroda acted as the friend, philosopher, and guide to the entire Project. He was the only person in the know of how the digitised exchanges worked due to his past US experience. The team needed intense training, Sam congregated them in Delhi and gave hours and hours of presentation explaining how to construct a Switch. He sent them to Chicago in batches so that work could continue in India. They trained in Bell Labs on Unix and C++. They also got exposure to the working of Bell, Motorola, and Intel and understood American work culture. Sam's egalitarian style of functioning was a force multiplier in an organisation of young people working against time. His importance on interpersonal relationships helped build faith and trust in the leadership. It smoothened work and increased efficiency.

The biggest challenge which Sam envisaged during the setting up stage was, the fear of the end product being more expensive than the solutions provided by a hoard of multinationals which had lined up their products in the Telecom Ministry, like Siemens, Ericsson, and Alcatel. The French company Alcatel was in the process of signing a deal with the telecom ministry of the Government of India (GOI); at the very moment Sam was establishing an indigenous production and setting up C-DOT. Thus, Sam feared that he would be beaten hands down should his product turn out more expensive than what Alcatel or others were offering. Sam knew that his scheme had an advantage. He planned a 'Rural First' approach before revolutionising the cities. It appeared financially prudent and politically correct. Yet he was obstructed at every step. The hold of the Foreign Companies was so strong on the bureaucracy that he had to use all his skills to keep the project on track.

He had planned to design small Switches: 128 and 256 lines – which could withstand Indian climatic conditions. The plan was: to have these switches maintenance-free once operational in the field. Create a pool of trained native young hardware and software engineers and manufacturing bases for the switches and ancillary products for the long-term sustenance of the exchanges. However, a surprise was awaiting Sam. When the product was ready the telecom ministry refused to accept it. 'Come through a tender', they stated. It took a demotion for Sam Pitroda from a MOS (Minister of State) to Telecom Secretary, to keep C-DOT alive.

The challenges for Sam were multiple. He had in his innings with GTE and Wescom designed digitised switches, and he knew he had the ware-with-all for it, but he was not in want of a few dozen, but between 30,000 – 60,000 rural exchanges, each of 128 lines capacity.

Manufacturing them, setting them up, and then maintaining them was a humongous task. He was grappling with a problem of huge capacities. Moreover, he had to start from scratch.

Sam explains the problem of working of the switches in India. Abroad in the West, switches work in an AC (Air Condition) environment, he explains. However, in rural India ACs are unavailable, and the power supply is erratic. Power supply failure would mean heating up of the switches in the absence of the air conditioning. The switches would blow out if heated. Sam's team circumvented this problem by using slow processors, which meant the time to route the call increased, but the heat generated was reduced. The small microprocessors also allowed for more space, thus increasing cooling in house without AC. The switches were ruggedised, making them bulkier, but they could withstand greater temperatures. Such methods of innovation, coupled with local solutions to suit Indian conditions, allowed the switches to be more effective even in a low-maintenance scenario.

With sustained efforts, an indigenous 128-line Switch exchange was ready to be launched. The initially announced capacity of production was: one RAX (Rural Automatic Exchange) per day. This figure was too meagre as it would mean 365 rural exchanges per year, and taking 30000-60000 exchanges could take anything between 80 to 100 years to complete the project, which was neither desirable nor sustainable as the technology would change even before the 10th year is reached. Enhancing the capacity was the only answer. Private participation was the only way out. Ultimately Sam and his team reached a production level of 10 RAXs per day, thus reducing the completion deadline by one-tenth on paper.

The idea of C-DOT was telephone connectivity in all villages. This desire manifested in yellow-coloured boards showing at first as an STD (Standard Trunk Dialling) booth, and an STD/ISD (International Standard Dialling) booth later. Individual owners operated the booths with a telephone. The telephone enabled an individual to dial any number in India and abroad. The call was charged, and the charge was displayed on the screen facing the telephone. When Sam quit the C-DOT programme, he had successfully set up a network of STD booths across India, and anyone could access and call. All this was achieved by his C-DOT team working with indigenous equipment. In his final report before the Indian Prime Minister, he dedicated the C- DOT project to the nation. He thanked the Prime Minister for his interest in the project and the support provided, without which this technological breakthrough could not be achieved in India.

What was unique about C-DOT?

C-DOT succeeded because it was unique. Sam worked on a strategy to start a telecommunication system laid from the bottom up. The generic argument in the global telecom industry was that telecom density is directly proportional to the wealth in the area. So, worldwide, as in India, the stress was on increasing telephone density in wealthy neighbourhoods. It meant better connectivity to the rich. C-DOT's mission was not to address the telephone density but instead to increase telephone accessibility. The argument was that if telecom accessibility increased, it would increase the wealth in that area. It was reversing the acceptable dictum of density. Thus, in India, where 70% of the population lived in rural areas, the necessity was to increase accessibility to villages. Telephone availability would increase connectivity and lead to greater economic activity. When ten villages are connected, the activity will not increase by 10X10 times but by 1010 times. That is the multiplier effect it will have. A similar strategy was used by the Chinese Telecom Company Huawei 30 years later.

The implementation of C-DOT involved developing and deploying advanced telecommunications technology, which was state-of-the-art. Developing indigenous technology for digital switching and transmission systems for rural communication posed significant challenges. It involved building small digitised exchanges of 128 and 256 capacities with indigenous manpower and material. C-DOT faced hurdles in developing complex switching equipment, setting up reliable transmission systems, and ensuring compatibility with existing infrastructure. For Sam Pitroda designing a Switch was easy as he had personal experience with both the GTE and Wescom days. However, its mass manufacture in India, where no private entrepreneur had ever designed or manufactured a digital exchange, was the biggest technological challenge. Also, the scale or the volumes involved in manufacturing were massive. Catering for six lakh villages meant provisioning 30,000 to 60,000 Rural Automatic Exchanges (RAX). Initially, the production capacity was one RAX per day, which would have taken a century to cover all the villages in India. The production capacity was enhanced ten times to 10 RAXs per day, thus reducing the completion time in theory by one-tenth. This increase in capacity was possible because of an out-of-the-box solution that attempted to call for private entrepreneurs to manufacture small digital Switches. Forty-eight entrepreneurs responded and were given contracts to manufacture the digital Switches. The C-DOT team prepared the designs of the Switches. They also provided technical guidance in setting up the manufacturing and testing facility. The sheer size and complexity of the technological challenge of indigenous manufacturing and greater volumes of RAXs made this project a unique achievement.

The government of India provided finance. A 36 million US dollars budget, in equivalent INR (Indian Rupee) 46 Crore, was allocated to the C-DOT programme. Nevertheless, there was a need to handle the budget and sub-allocate it to numerous subsidiary heads. Ensuring proper funding for the project and managing resources effectively was a challenge. C-DOT being a horizontal organisation, there was a need to decentralise the budget. Delegation of financial powers was resorted to for quick decision making and procurement.

For his outstanding contribution to Science and Engineering, Sam Pitroda was conferred with Padma Bhushan by the Government of India in the year 2009.

Learning from Sam Pitroda's C-DOT Experience

- **Dream.** It is essential to have a big dream: A Vision. And when you dream, dream big. For Sam, it was a dream of 'Connecting India': To bring a telecom revolution to the country.

- **Visionary Leadership.** Any revolutionary project needs a leader who has the requisite technical knowledge and ability to execute the project. Without such a leader, a high-technology project cannot take off. In Sam Pitroda's case, he was technically qualified, having worked in the US on switches in a telecom company. Moreover, he had the experience to train a team required for the job. He had worked in the best telecom companies in the world and understood the nuance of using the cutting-edge technology for telecom projects. Sam was a 'High Achiever'. Sam found an ideal partner in the then Prime Minister of the country Rajiv Gandhi, who shared his vision and provided the visionary leadership to fulfill his dream of 'Connecting India'.

- **Passion.** It is essential to have the passion to drive a project from start to finish. In Sam Pitroda's case, he left his lucrative job in the US to start a telecom revolution in India. He battled through all the stages -- from the drawing board to establishing STD booths, he stayed steadfast in his desire to connect India through telephones.

- **Challenge.** The project was a technological challenge as setting up small RAX involved making more miniature Switches and making them work in local conditions. Sam and his engineers modified the Switchboards using slower ruggedised processors, which would work in hot and humid conditions without an AC.

- **Independent Entity.** For Sam Pitroda, the vision to have a separate entity for C-DOT independent of government, yet be sponsored by it, was critical to its success. Such an extraordinary arrangement was possible only because the need demanded it, and the political leadership saw the possibility of it succeeding. Working with the government is an art. The leader should know about how governmental systems work. In C-DOT's case, Sam was very clear that it had to be a government-funded project due to the sheer scale of the rolling out of the project. A total of 6 Lakh Indian villages needed between 30 to 60 thousand 128 lines RAXs. Any private enterprise would be incapable of handling such mammoth scales during that period.

- **Facing Odds.** The project faced hurdles at every step. The indigenous product was usurping the space from the foreign vendors. It led to acrimony and bureaucratic interference. Even media was brought into the fray to announce how the indigenous dream was a big hoax. Sam Pitroda was accused of being a CIA (Central Intelligence Agency) agent wanting to sabotage India's progress. Due to the technological gap, foreign vendors from European and American markets ruled the roost for import of telecom equipment from the West. Their influence in the corridors of power in New Delhi was immense. Amidst all this, one man's resolve held firm and he fought the odds to prove them wrong in the end.

- **Autonomy.** Being an autonomous organisation, C-DOT faced a challenge of coordinating with the lead ministry, i.e., Telecom, and other supporting ministries like Industrial Production, Finance ministries and a few others. Two factors helped C-DOT -- first, it had the Prime Minister's backing and second, its goal of digitising rural India was a powerful political motive.

- **Human Resource.** It is the most critical element in execution of any project, especially for the telecom and IT (Information Technology) industry. Good engineers are very hard to find. Even after finding the desired resources, how quickly they can absorb new technology and work long hours determines their success. The USP (Unique Selling Point) of C-DOT was the hiring of talented young engineers who had a desire to succeed. In the process, they were willing to learn and think out of the box. They were not afraid to make mistakes and gave their hundred per cent for the project.

- **Management of Human Resource.** For the leader, managing human resources is crucial to unleashing their true potential. It is only as good as he/she is allowed to be. Constant guidance and motivation are essential for humans to tap their inner strength. In the case of C-DOT, Sam assembled the team and trained them. He was a source of constant motivation for them. He inspired them to give their best and reap the harvest together. He stood by them in their bad times and credited them for their achievements.

- **Resolute.** Be undeterred by criticism when working on anything new, especially cutting-edge technologies, which most stakeholders do not understand. Criticism was expected initially, in the middle, and even after completing it. A team has to be thick-skinned to work amid the criticism. In Sam's case, he was under attack from all sections of the public. However, he did not allow criticism to shape his response in pursuance of his goal. He showed faith in his abilities to pursue his goal and carried his team along with the same fervour.

- **Political Support.** It helps to have political support. The full support of both PMs: Mrs Gandhi and Shri Rajiv Gandhi helped C-DOT to tide over rough weather. The political nod allowed the project to roll out despite many interest groups opposing it.

- **Mass Production.** It was the big challenge to produce the RAXs in large numbers. India was living in the era of public sector industries, and participation in strategic assets of Private sector was not a norm. To get multiple vendors to participate in manufacturing RAXs of same size and standards was a huge challenge. The private manufacturers had no skill and technical knowledge to manufacture digital exchanges. Sam Pitroda's personal involvement along with his design engineers who hand held the entire manufacturing process to mass produce the RAXs. The ability of the C-DOT team to find multiple homegrown suppliers for the digitised switches and telephone instruments was one of its most significant achievements. It was an impossible task to make 30,000 exchanges of similar standards in India, without the team's involvement.

- **Finance.** Finance is the biggest driver for innovation and implementation of cutting-edge technology projects. Sam Pitroda secured a 36 million dollars US budget for his C-DOT Project, which was a significant achievement. Without the governmental financial support, the project would have been a non-starter.

- **Future Applications.** The C-DOT programme had the potential for future applications—all BSNL (Bharat Sanchar Nigam Limited) civil and military telecommunications applications now run on C-DOT platforms. Today, C-DOT is in collaboration with French company Alcatel-Lucent in research for the broadband of the future. C-DOT adapted its indigenous technology for deployment in foreign countries: Vietnam, Egypt, Iran and Bhutan. C-DOT has matched its products to the best available globally through indigenous resources.

Amitav Mallik: High-Powered Laser and Direct Energy Weapons

(HPL & DEW)

Star Wars movies and Star Trek TV series have defined the adventures of outer Space for decades for mankind. But Space is no longer a frontier that can be confined to fantasy or fiction. It is a paradigm already conquered by humans. The future wars could well be in Space. It is thus not surprising that India is contemplating setting up a 'Space Command'. The journey to weaponise Space started in the Cold War era, when US President Reagan decided to stalemate the USSR (Union of Soviet Socialist Republics) with a better strategy. The strategy was to destroy Soviet nuclear missiles in space during its flight. This strategy ended the era of deterrence through MAD (Mutual Assured Destruction), and gave birth to a new initiative. It was called the 'Strategic Defence Initiative' (SDI); its popular name was 'Star Wars'.

Concept-wise, it was a sound idea; however, to put it into practice demanded the use of cutting-edge Technology, the latest, in every field. The Technology was called the 'High-Powered Laser and Direct Energy Weapons'. Since then, both the Soviet Union, now Russia, and the US have been taking rapid strides in this field. Many countries have joined them: China, Israel, Germany, and India. For India, it was pioneered by Prof. Amitav Mallik, who has singlehandedly led the 'Star War' initiative. A research scientist, he was amongst the first in India to work on Lasers. Prof. Mallik is also known as the 'Father of Lasers' in India, and he got us closer to the 'SDI' dream through his work on HPL & DEW.

What is HPL & DEW?

The two terms, High-Powered Lasers (HPL) and Direct Energy Weapons (DEW), are combined to form a Potent weapon system, which can be best compared to the destructive third eye of the Indian deity Shiva. The Hindu mythology believes Shiva opened his third eye to destroy evil beyond others to combat. The term 'Evil' could be synonymous with the modern-day nuclear weapon. The challenge is twofold: First, to produce a laser beam over 100 kW (kilo Watts) that will cut through any matter that comes in its way; and second, to mount it on a platform that will support its carriage and deliver the beam to the intended target to create the desired effect. Both use complex technologies and have a massive R&D (Research and Development) ongoing in their respective fields.

HPL: The high-powered lasers for military use require a high-powered laser beam which, when directed at the target, would create structural damage to the enemy's weapon system, rendering it ineffective if not destroyed. The creation of such a high-powered laser beam requires a high-energy source. Usually, when operating in the field, this energy source is either a gaseous or chemical reaction. The generation of such high-powered energy poses a problem and has concomitant effects. The thermal management, beam control, optics, sensors, and control electronics all come under severe stress and need specialised arrangements to function efficiently.

DEW: Direct Energy Weapons is a weapon platform that delivers an electromagnetic warhead on an enemy target. A target could be an enemy missile, a sensor platform, or a satellite based in Space. Many DEWs exist -- from a simple ground-based platform to a drone, or an aircraft. In 1980, the US Air Force used a KC 35 Transport aircraft to deliver a CO2 Gas Dynamic Laser (GDL) on an incoming missile. A significant boost to DEW came in 1983 from President Reagan's SDI programme when newer technology was experimented to destroy a potential Soviet nuclear-tipped ICBMs (Intercontinental Ballistic Missiles) mid-flight. Extensive research in DEW systems has pushed the technology envelope to a new level, where fully configured DEWs with HPL will be deployed in space as part of a nation's missile defence systems.

India's Story of HPL & DEW

The journey of High-Powered Laser (HPL) and Directed Energy Weapons (DEW) began for Prof. Mallik when he was a Senior Research Officer at the Solid-State Physics Laboratory (SSPL), Delhi. His pioneering work on indigenous high-power Helium-Neon Laser for Nuclear spectrographic applications brought him India-wide recognition in 1974. Meanwhile, the US-USSR Cold War graduated to the Outer Space capability race, and US President Reagan announced the Star War Programme in 1983 under the Strategic Defence Initiative (SDI). Immediately, most space-faring nations began high-power laser R&D. Prof. Amitav Mallik was selected to lead the HPL R&D at the Defence Science Centre, Delhi, in 1985.

In a rare break, Prof. Mallik became the first Defence Technology Adviser for India at the Embassy of India in the US, Washington DC, in 1988. His brief was to reverse the US-led 'Technology Denials' to India for any high-end technology. His job was to scout for cutting-edge defence technology for India, when the Cold War between the US and the USSR was at its peak. That was the time when India faced severe technology controls. It was the job of the new Indian defence Adviser at the Indian Embassy in Washington DC to understand the level of advanced Defence technology status in the US and present India's case for the purchase of advanced defence systems and related technologies.

In those days, the US had a “Presumption of Denial” policy for sharing Technology with India and other Soviet-bloc countries. The approach was first to say ‘No’ and then examine if there is any commercial or strategic confluence of interest to pursue the case further. The example of the denying the supercomputers to India was a typical case. Successfully resolving many Indo-US high-tech cooperation, Prof. Mallik got approval for hundreds of denied technology subsystems. He was thus asked to continue in the US for three more years to a full six years. As a senior Indian Diplomat in the US, Prof. Mallik had many opportunities to interact with Industry leaders, including in Laser Technology, to update his expertise on the subject.

In 1996, the reported use of US land-based High-Powered Laser (HPL) to destroy their decommissioned satellite brought instant awareness of the vulnerability of all low-earth surveillance satellites of all other nations. India thus started preparing for Satellite Defence technologies with HPL.

Having acquired the requisite understanding of using HPL in various applications, Prof. Mallik was back in Delhi as the OSD (Officer on Special Duties) to Dr Abdul Kalam. The Cabinet Committee on Security (CCS) called for a severe brain-storming with Dr APJ Abdul Kalam, the then Scientific Adviser to the Defence Minister, and Prof. Mallik. With Prof. Mallik’s experience in indigenous High-Power Laser and his six years in Washington DC, USA, he was best suited to present the technological challenges for developing an Anti-Satellite HPL Technology Demonstrator in India. In that CCS briefing, with Dr Kalam present, Prof. Mallik was asked to present the highlights of his US stay and takeaways for India.

Taking note of his briefing regarding anti-satellite weapons development, the CCS issued a directive to Dr Kalam to start a Counter Satellite Space Defence Programme for safeguarding Indian assets in Space. The timeline was five years, to keep pace with the R&D in China. It was a tall order as the requisite Technology was unavailable even in a nascent form. Post the discussions, Prof. Mallik was responsible for undertaking and operationalisation of the Counter Satellite Space Defence Programme. Dr Kalam fully trusted Prof. Mallik and asked him to set up a project team under his guidance. Two terms of reference emerged: first, the urgency, and second, the need to keep the ‘Defence Technology Project’ confidential.

The new lab was named the Laser Science & Technology Centre (LASTE P09843C), was set up in the Metcalfe House in Delhi, and that was the start of the Indian HPL-DEW Programme.

The task at hand was difficult because it involved the generation of High-Power Lasers and the direction of the same as a beam to a distant target in space, such that the target is decimated (Unfit for Operational Use). Production of such a high-power laser involves a high source of energy, such as nuclear or gas-based. No one in the country had researched high-power lasers as the same did not provide commercial benefits, not even the DRDO (Defence Research and Development Organisation), for it lacked the requisite leadership and knowledge.

In this context, Prof. Mallik's role must be appreciated. He spearheaded the technological implementation of the project. He used innovative measures to ensure the project took off from the ground. His biggest challenge was getting a qualified workforce of scientists and engineers to run the project. It was obvious to him that technical knowledge of the subject would be missing. Yet, the propensity to learn and the ability to apply it to the task assigned was the critical factor for choosing candidates. For such niche jobs, selecting candidates would require an organisation with adequate experience, suitably qualified, and staffed. However, there was neither the time nor the availability of resources for such an option.

Prof. Mallik sought a most ingenious method to solve this problem. He was a good friend of Dr Bhawalkar, the Director at Centre for Advance Technologies (CAT), Indore, of the Atomic Energy Commission (AEC). The AEC was known to recruit 250 top scientists/engineers from a selected list of 500, the best available candidates in India every year. In consultation with Dr Kalam, Prof. Mallik requested the Chairman of AEC to give DRDO the names of the next best 250 candidates not recruited at CAT, Indore. This second best was the pool of talent Prof. Mallik recruited for his HPL & DEW Project. He set up training centres and sent some young scientists to Russia to learn from the Russian experience in the same field. He also sought Russian assistance in providing the initial breakthrough for the Project. Three Indo-Russian joint teams were formed to assist the work at LASTEC, Delhi. One team to assist with the HPL source of 100 kW power, the second team with a very sophisticated Beam-Directing Subsystem for aiming the HPL to the selected moving target at 600 km in low orbit, and the third team to assist in the integration of all systems at the control electronics centre. The IITs (Indian Institutes of Technology) and leading universities with expertise in large 50-cm aperture Beam-Director Optics were awarded special technology contracts. The confidence to achieve success was so high that a team which should have been set up in the end, i.e., to mount the system on heavy-duty Tatra Trucks for test firing, was set up at the beginning of the Project, with the help of R&D Engineers in Pune.

It was a near-impossible task to achieve within five years. However, the LASTEC team of over 700 scientists, engineers and workshop workers under the leadership of Prof. Mallik were driven by the national ambition of getting ahead of China. In over four years, the prototype of Indian Laser-based Beam Weapon technology demonstrations was ready and named 'TRINETRA', signifying the 'Third Eye of Shiva'!

There were many hiccups in the completion of the project. Ultimately, India's DEW technology project demonstrator was trial-tested in simulated conditions at the Hindon Air Force base near Delhi. This demonstration to the members of the CCS and other heads of services, the DRDO, and a few more important ministers in October 2001 was a complete success. It was still a 'Secret' hush-hush project as the government did not want to make it public. Indian plans to develop HPL and DEW weapons were a sensitive issue for international audiences, especially for the US, Russia and China. By then, China had been trying to acquire HPL technology from the Russians. At that point, India was ahead of China in HPL & DEW. Today, it is a different story. The Use of HPL and DEW in a simulated manner demonstrated that India had developed with indigenous resources a satisfactory level of HPL, and the ability to direct it to a target on land and Space for short distances.

HPL and DEW: A Saga of Innovation

The technology demonstration was essential to show to the decision-makers and the powers who possessed this technology that, given the political will, India could effectively launch an HPL-mounted DEW in air or space. It would have otherwise only remained a threat on paper. A technology demonstration transformed it into being.

It was a complex project to accomplish through indigenous resources. It thus required many innovations and home-grown solutions. Since the project components and knowledge were under 'technology denial' regimes, it was necessary to innovate; starting from which type of HPL was best suited to India: was it the CO2 Gas Laser or the Chemical laser? The study of Laser-Target interaction was another factor in selecting the form of Laser to be used. Hence, a strategic decision to first develop the CO2 Gas Dynamic Laser of 100 kW power, capable of 1-2 second bursts for softer targets like Low-Orbit Satellites at about 600-km range, as well as Surveillance Drones at much shorter distances, was taken. The power requirement was set for 100 kW of 1-2 second bursts for optimum kill possibility for the prototype Beam Weapon system. Measuring the power output was another challenge, as the beam would damage any detector in its path. An indigenous gadget consisting of 1/8th inch of blackened iron plates was deployed such that one kW of power-produced CO2 HPL would puncture them in one second. Eventually, the number of such plates were stacked, which a 100 kW of CO2-based HPL would puncture, thus measuring 100 kW power.

Another challenge was directing such a high-power beam to a distant moving target at a 100-km range. Indigenous visible laser-based optical Radar was developed for precision tracking of moving targets. Then, the invisible HPL beam director was slaved to the optical Radar for accurate target tracking and shooting with servo-controlled high-precision shooting.

Beam-director optical design was another challenge that required intricate, innovative skills. The metallic Beam-director of 50-cm diameter was fabricated at Pune University, and BEL (Bharat Electronics Limited), Machilipatnam. Because the final beam director was a highly polished complex metal mirror in smaller sections, actuators were mounted from behind to provide adaptive control to minimise atmospheric transmission effects for the high-power beam to achieve focus on distant targets. All this was an indigenous effort involving the best technicians at IRDE (Instruments Research and Development Organisation), Dehradun, the Universities of Pune and Jadavpur, and some of the IIT workshops.

To have produced this indigenous effort was an achievement that stood out, easy to notice by both the superpowers. It required a controlled lab environment to produce the high-density Laser and involved Indian minds in finding an indigenous solution to the complex phenomenon of high-powered lasers. These complicated processes were beyond the reach of moderate technology-endowed nations. The complexity increased when the need arose to mount the system on a small mobile platform on a surface, in air, or space. Such endeavours were seen beyond the reach of indigenous efforts in India, in the eyes of the Western powers.

To have surmounted these problems with an indigenous workforce and resources is a tribute to Prof. Mallik and his team's innovativeness and tenacity. The capability demonstration was the foundation of the effort, creating a potential for scaling it up to a larger scale later. It could mean a higher-powered laser with a longer-distance beam-directing capability. Technology was available to take the programme ahead. Prof. Mallik's feat and his team's achievement have no parallels, as they thrived in a world of sanctions and non-cooperation by Western nations. To dare to do a project against the advice of well-wishers in an era where technological innovation had not reached India, where dealing with analogue Technology was the high point, was a true harbinger for 'Atmanirbhar Bharat'.

For his outstanding contribution to the field of Lasers and Defence Technology, Prof. Mallik was awarded the Padma Shri by the Government of India in the year 2002.

Learnings/Observations from Prof. Amitav Mallik's HPL & DEW Project

- **Leader.** Prof. Amitav Mallik led the project. He was the driving force. Once again, this proves that a qualified and capable man determined to succeed can master any technology. One man's vision and commitment brought this cutting-edge technology to India's armoury. He conceived it, planned it, and he implemented it.

- **Vision.** It is the most essential element of a successful venture. The vision in this case study was to give India a capability in the field of High-Power Lasers as instruments of defence for national security.

- **Exposure to Newer Technologies.** The field of HPL & DEW was an exclusive domain of the superpowers in the 1980s. No developed country, let alone a third-world country, was given access to its Technology. Prof. Amitav Mallik's stay in the US, where he interacted with the industry in the business of lasers and their applications, gave him an insight into where the field was heading. That knowledge was extrapolated to start a project for the country when asked by the CCS.

- **Government's Working Ethos.** Two noticeable events enabled the HPL & DEW capabilities to be mastered in India. First, after adequate exposure in the US, Prof. Mallik was posted back to the right ministry, the Ministry of Defence, and second, he was placed under the right mentor: Prof. Abdul Kalam. The combination ensured Prof. Mallik got an audience with the CCS and, on their recommendation, a chance to execute Project Trinetra. Two lessons emerge for government agencies: First, recognise talent, and second, place it under the right people for it to deliver.

- **Innovation.** Project Trinetra was a work which was innovative in its entirety. It was nothing like anyone had attempted in the country. Even in conception, it was one man's dream that could not be shared with many due to the sensitivity of the project for national security. The lesson that emerged is that if the conception is correct, India has the will and the talent to start a project from the ground up to the space. Production of high-power lasers, type of laser to be produced, the mode of its delivery, the integration of the two, and doing it in a close confined area, all these and more were works of pure innovation.

- **Qualified Workforce.** Prof. Mallik adopted the novel and practical method of gathering qualified talent. Given the shortage of time and resources, this ingenious method bore fruit. It also tells us that even when given the second-best, Prof. Mallik could extract quality work from them, busting the myth that there is not enough talent in the country. The second-best were better as they achieved critical success. However, it also exposes the lack of institutions dealing with high-quality talent or nurturing them, especially in defence technology.

- **Support of the Government.** A project of this complexity cannot be attempted without government support. The government of that date deserves equal credit for having recognised the need for such a project and sanctioned Prof. Mallik the funds and the approval to pursue the creation of LASTEC, which led to Project Trinetra. The lesson is that strategic projects require government support to fructify. They must entrust the right person for the job and give him the desired funding. In this case, it was INR 300 Crore.

- **Confidentiality of Project.** The project classification is 'Secret'. This classification meant that the project objectives were known to only the core group headed by Prof. Mallik. The project was divided into subsystems. Only the subsystem designs were known to the respective team engineers. Smaller components were developed independently of the others. Indigenous labs and industry were also involved but did not know the end objective. It was finally assembled at one place under the leadership of Prof. Mallik. The lesson is: A confidential project implementation through indigenous resources without involving foreign vendors is possible. The capability to make the secret weapon exists in the country, as shown by Prof. Mallik.

- **Creating a new Lab.** A new lab, LASTEC (Laser Science and Technology Centre), was created while employing 200 engineers within two years. It was an unparalleled feat. Done with government sanction, Prof. Mallik's team worked in this Lab to create the HPL & DEW system for India. The sanction, selection of the place and setting up a complex lab was a new high for the country, which was still on the lower end of the technology and innovation cycle. A lesson in this is to allow technical innovation to flourish in India such that upcoming entrepreneurs do not need to go abroad for research. They can find the infrastructure required in their own country.

- **Future Applications.** HPL & DEW has applications for the future. Space is the next dimension, and using space for military and commercial applications will guide future technological innovations. Guarding one's assets in space would thus become a national security requirement. India is among the few countries that possess this technology. Since this domain is in the realm of confidentiality due to the competition among the nations possessing the technology, its commercial proliferation has not yet begun. It is a matter of time before it happens, and India would do well to keep gathering knowledge and improve its current capabilities in the field.

Arogyaswami Paulraj: APSOH (Advanced Panoramic Sonar Hull Mounted)

On 7 December 1971, INS (Indian Naval Ship) Khukri, an Indian Frigate ship, was torpedoed and sunk by PNS (Pakistani Naval Ship) Hangor, a submarine, 40 NM (Nautical Miles) off the coast of Diu in Gujarat. INS Khukri along with INS Kripan were hunting for an enemy Daphne-class submarine in the Gulf of Khambhat off the coast of Gujarat. If the Indian Navy had a more sophisticated Sonar, it could have detected PNS Hangor before it struck the fatal blow. But unfortunately, the Sonar technology with the Indian Navy had not reached the level where it could have detected the modern, made in France, Daphne class submarine, PNS Hangor. Amongst the crew that went down with the ship was Lt (Lieutenant) Jain, who was sitting onboard the INS Khukri's Sonar room trying to detect the Pak hunter-killer Submarine with his latest retrofit model of UK-made Sonar 170B, built with the help of BARC (Bhabha Atomic Research Centre), Trombay (Bombay). Lt Jain and a team of BARC scientists were experimenting with using a new Sonar technology called the Ping to Ping Integration (PI). It was good, but not good enough to succeed in war.

Sonar is an acronym for Sound Navigation and Ranging. It is used for exploring and mapping the ocean. It has extensive applications for the Navy, detecting underwater moving or stationary enemy vessels/objects, especially submarines.

The sinking of INS Khukri was a big blow to the Indian Navy. They summoned all their punches to ensure that a repeat did not take place. Lt Paulraj, an NDA alumnus and an electrical officer in the Indian Navy, was pursuing his PhD from IIT Delhi on the day INS Khukri sank. The morning after, Lt Arogyaswami Paulraj was summoned to Bombay to give his opinion on the BARC Sonar module, which was mounted on the Khukri before the war. Lt Paulraj's PhD thesis on Signal Estimation theory was related to Sonar. Moreover, his approach was different from the BARC model. Paulraj thought that the technology used in the BARC Sonar was restrictive and retrograde, hence failed to detect the Pakistan submarine. To take a new approach to Sonars, the Navy asked him to take up and improve the project. This new project was the beginning of the journey for APSOH.

Early Years

Studying the early years of Lt Paulraj is essential to understand that educational institutions alone do not make scientists. The inherent love for the subject and a passion for learning outside the curriculum make outstanding innovators. Lt Paulraj joined the NDA (National

Defence Academy) Khadakwasla very early. Those days, NDA did not even have an education degree tied up with any university. He selected the electrical branch in the Navy as his core professional stream due to his love for pure mathematics and physics. He pursued his BTech from INS Shivaji, the training school for Electrical branch officers of the Indian Navy. During the course, he found his course curriculum very basic; hence, he studied subjects that were in the MTech curriculum. He was brilliant in academics, and his performance in professional courses was outstanding. He was selected to do an MTech course at IIT Delhi based on his professional performance.

During the selection, an interview board member, Professor Indirasen, took an instant liking for him and took him under his wing. At the beginning of the MTech course, Professor Indirasen recommended to the IIT Academic Council to upgrade Paulraj to a PhD programme. He argued with the board that his pupil has already studied the MTech curriculum. IIT Delhi agreed after a bit of persuasion from Professor Indirasen. However, the Navy had the strongest objections. They wanted him back as early as possible. Professor Indirasen's request to VCNS (Vice Chief of Naval Staff) paid dividends, and the Navy relented.

Lt Paulraj chose 'Signal Estimation Theory' as his PhD doctoral topic due to the influence of his visiting Professor, Tom Kailath. Tom was a visiting Stanford Professor at IIT Delhi. He had lectured on the subject. The topic was complex, and Paulraj's approach was abstract. That set him apart, and even the visiting Professor was impressed with the PhD work of Lt Paulraj. The PhD doctoral subject became the foundation for the success of Model 170B, and later APSOH.

After completing the MTech (PhD) period, Lt Paulraj was posted to INS Valsura, in Jamnagar Gujarat, awaiting his sea time. However, due to his mathematical-heavy thesis, he was desperate to be in a place where he could access a library. He had accordingly put up a request to his higher HQs (Head Quarters). Finally, to the utter delight of Lt Paulraj, the Navy relented and posted him to Naval HQs in Delhi, where he could finish his thesis. He continued to stay on the IIT campus, in his old quarters and from where he had an easy access to the library after his office working hours.

That changed on 3 December 1971, when the Bangladesh war broke out with Pakistan. On the evening of 7 December 1971, INS Khukri perished to a torpedo, as explained earlier. Lt Paulraj found himself in Bombay taking over a new Sonar project of improving the Model mounted on the INS Khukri, the 170B Sonar. IIT Delhi was the nominated lead agency to drive the project under Professor Indirasen and an IIT research team. Lt Paulraj led this research team, which was a blessing in disguise. Paulraj now had access to a budget, where he had the freedom to import electronic components of his choice. They imported digital and analogue ICs (Integrated Chips). The team built a new transmitter and receiver using a different method.

With that, the team modified the Sonar Model 170B and produced it for multiple sea trials. The trials confirmed the improvement in the new Sonar model as its performance improved dramatically. The Navy accepted the new design of Model 170B in 1973. The design was transferred to the production agency, BDL (Bharat Dynamics Limited), Hyderabad, for volume manufacture. As per Lt Paulraj, the new design of Model 170B was India's best work on signal processing technology until that date. The success of 170B Sonar changed the perception of the Indian Navy about the potential of the technical talent of its officers. It also was a payback to the nation, vindicating huge investments into higher education institutes like the IIT Delhi.

Having successfully completed the 170B project, Paulraj was allowed to pursue a one-year attachment with the UK University of Loughborough at the behest of Professor JWR Griffiths. The Professor from Loughborough University was a visiting Professor at IIT Delhi and was aware of his PhD work. Lt Cdr (Commander) Paulraj joined Loughborough University in 1974. There, he met Professor Herman Bondi, the chief scientist for the British Ministry of Defence (MOD). At his behest, he lectured many British MOD labs on his PhD work. He also had the opportunity to visit and see many Sonar firms in the UK and France supplying equipment to the Indian Navy. During these visits to the firms, Lt Cdr Paulraj realised that the Sonar teams at these firms had very little understanding of the subject of Sonar signal processing. Based on his experience with 170B and his PhD work, he helped them improve their Sonar designs. He returned to India in November 1975.

APSOH

Lt Cdr Paulraj's experience in the UK of Sonar development convinced him that the Indian Navy should design and develop its indigenous Sonar model. After his return from the UK, Lt Cdr Paulraj was due for his sea time, and was awaiting orders. Having understood the importance of Sonars, the Navy decided to use Lt Cdr Paulraj's knowledge and experience. They posted him to the DRDO lab: NPOL (Naval Physical and Oceanography Lab) at Kochi. He lobbied for building a next-generation Panoramic fleet, Sonar, with the naval HQ. The Navy had already decided to import a new Sonar and was on the verge of striking a deal with the French company Thompson-CSF. Lt Cdr Paulraj pleaded with them for an indigenous Sonar. He cited the example of the successful modification of Sonar Model 170B, which had passed the sea trials with flying colours. Also, he narrated the status of the UK and France's Sonar development, which was behind what was being developed in NPOL. Thus, in 1976, Dr Srinavasan, Director, NPOL, and Paulraj convinced the naval top brass to build an indigenous Sonar. It was a leap of faith. NPOL had no track record to justify such a large and ambitious project. A CCS paper was drawn, and approval was sought to design an indigenous Sonar. The project got approved, with a budget of 280 Lakh INR. The NPOL Lab Director, Lt Cdr Paulraj was designated as the team leader for the new Sonar design team.

Thus, project APSOH was kickstarted. Cdr Paulraj was a full-time Project director, chief scientist, Chief Engineer rolled into one. His main job was project coordination and system design verification. His team grew from ten to 60 from 1976 to 1982. Working on the new Sonar system had its set of challenges. Not only were they creating a new generation of Sonar, but they were also battling the import regime of the government. Computers had just come in, and with them came the advent of microprocessors. Sonar of the type the team hoped to design required fast computing to control the interface and the diagnostic functions. At that point, the Intel 8080 processor seemed to fit well. The Indian government strictly controlled imports of all semiconductor parts like microprocessors. It required government sanctions to import them. The Electronics Import Control Department of GOI decided that the Navy did not need microprocessors. Hence, the import of Intel 8080 was denied to the research team. The team used some ingenious methods to circumvent the problem. Those days, the computer building blocks known as slice-bit processors were available, and the import regime did not ban their import for lack of computer knowledge. The team imported the slice bit processors and added components to configure a new design. The innovation converted the slice bit into a powerful microprocessor. This new microprocessor was critical in the design of the new Sonar. In the bargain, the NPOL team controlled the microprocessor technology. It could add features to suit Indian conditions, such as the temperature sensitivity control missing in the original Intel 8080. The innovation was successful, but it imposed penalty both on time and money.

By 1982, six years later, after some ingenious work and many toiling hours, the APSOH was ready for sea trials. INS Himgiri was the ship chosen for the sea trials in mid-1982. Within the first few days, it was clear that the system was far superior to anything the Navy had used. It achieved a range of detection of a submarine up to 16km, unheard of till then. There were minor problems, which were resolved in situ. The system performance was beyond expectation, and its quality was comparable to the best. It was more advanced than anything that was in service either in the Soviet Union or in Europe. Comparison to the US was impossible as no data on the American in-service Sonars was available.

The Navy accepted the design for volume production. However, there were serious problems between the DRDO, the Navy, and the Production agency BEL (Bharat Electronics Limited), Bangalore. The highest offices in the Navy had to intervene to resolve the issue. The result was that Cdr (Commander) Paulraj had to quit the project. Once the Navy accepted APSOH, Cdr Paulraj went on a two-year sabbatical to the US, Stanford, where he continues to work even as on date. At Stanford, Cdr Paulraj exceeded all his expectations, formed two companies, and listed 79 patents (individually and in partnership). Being the founder of the MIMO (Multiple Input Multiple Output) technology, which is the core principle behind today's 4G and 5G networks, he was awarded the highest award in the field of telecommunications: The Alexander Graham Bell Medal in 2011 by the IEEE (Institute of Electrical and Electronics Engineers). He is also the recipient of the Marconi Prize, an equivalent of a Nobel for Technology pioneers.

After his return to India from Stanford, Cdr Paulraj founded three labs: The CAIR (Centre for Artificial Intelligence and Robotics) and the CRL (Central Research Lab) for Bharat Electronics, and co-founded the C-DAC (Centre for Advanced Computing). In between he was attached to the Air Force's LCA (Light Combat Aircraft) development programme. He quit the LCA programme because of his differences with the DRDO. This sudden departure cost the nation 25 more years to develop the LCA. In 1991, he returned to Stanford due to the excessive bureaucratic tussle that his presence created in government organisations. His move back to Stanford, this time for good, was a significant loss to India's scientific community. The then CNS (Chief of Naval Staff) Admiral Tahiliani commented: "The circumstances that led to his move explain why India has so few Nobel Laureates".

APSOH and its future variants continue to remain the mainstay of the Indian Navy even to date. Its design was more advanced than any contemporary Sonar, either with the UK, France conglomerate or the Soviet Union/Russia. Even after almost 40 years, its design is still secret as it continues to remain in service on all Indian Navy ASW (Anti-Submarine Warfare) ships. For his outstanding contribution to the Indian Navy, Cmde Paulraj was awarded the Padma Bhushan in 2010.

Lessons from the Achievements of Cmde Paulraj

- **Extraordinary Man.** To achieve success which transcends the ordinary requires a man of extraordinary abilities: a high achiever, to drive it and impart momentum. Cmde (Commodore) Paulraj, a man of extraordinary capabilities and brilliance, led a project which provided to the Navy the best Sonar in the world. The model and its variants are still the mainstay of the Indian Navy. The APSOH was built in NPOL but the brain behind its design was Cmde Paulraj.

- **APSOH Team.** The APSOH project was a project led by Cmde Paulraj but delivered by his team at NPOL. Cmde Paulraj himself attributes the success to his team. The team worked day and night for six years before APSOH fructified. The Lesson emerges that if led by a sound leader, a team can produce outstanding work. Paulraj, in one of his interviews, is quoted to have said, "I am always amazed as to how such an inexperienced team, with such few resources, pulled off this major project in such a short period. APSOH was an impossible dream that came true for many of us."

- **Out-of-the-Box Thinking.** Thinking out of the box. Cmde Paulraj always looked for newer ways to find a solution. He very seldom traversed the beaten path. His approach for his doctoral thesis, Signal Estimation Theory, proved to be a path-breaking discovery on which he had based his modification of the 170B Sonar. His PhD work in IIT suggested three techniques to upgrade the Sonar: Linear Frequency Modulation, Noise reduction using DODN (Digital Own Doppler Nullification) and Notch Filtering (NF). The three combined improved target visibility, removed target echoes and reduced noise. All this in one ping. Cmde Paulraj's method proved effective and was accepted by the Navy. A newer model of 170B was thus available to the Navy, thanks to Cmde Paulraj's innovative thinking. He later made a similar pitch in discovering wireless signalling with his MIMO technique, for which he was awarded the Marconi medal and IEEE Alexander Graham Bell Award.

- **Restrictive Government Policies.** Restrictive policies are a deterrent for innovation. The APSOH team at NPOL were denied the import of the latest microprocessor chips Intel 8080 for lack of understanding of technology by the bureaucracy in the Electronics Import Control Department of GOI. The denial cost the government in time and money. The NPOL had to circumvent the process to fulfil the processing need of the state-of-the-art Sonar.

- **Innovative Spirit.** The innovative spirit of the team and the leader was crucial for the success of the APSOH project. The circumventing of the problem of denial of permission for the import of computer microprocessors by government agencies was a unique example of high-class innovation. Importing the slice bit chips and rejigging them into microprocessors to suit the Indian environment was why APSOH was such a resounding success.

- **Academic Qualification.** His PhD work prompted Professor JWR Griffiths of Loughborough University to offer him a seat as a Research fellow at the university. Success thus opens many doors. His meeting with the Chief Scientist for the British MOD, Professor Herman Bondi, opened doors for his visits to many Sonar-producing labs and industries in the UK and France. It gave him a good insight into how the British approached the Sonar field. This insight led to his discovery of the superiority of his and India's work on Sonar over their contemporaries. Without this insight, the confidence to undertake a complex Sonar like APSOH was unlikely.

- **IITs in India.** IITs have done yeoman service to the nation and the vast pool of scientific talent. The IITs selected and trained the best scientific brains in India. Unfortunately, in those days, all the IIT-ians dreamt of working abroad, like in the US. What was then known as the 'Brain Drain'. Today, the situation may have changed, yet many wish to work abroad as the chances of working on cutting-edge technological innovations exist more outside India. The Lesson is to create adequate incentives to hold this precious human resource in India for the indigenous industry.

- **Importance of Mentor.** Cmde Paulraj's respect, and his undying faith in his IIT guide and mentor, Professor Indirasen, and later Professor Tom Kailath, is lesson for all to emulate. He held them in the highest esteem and went back to seek their support at every opportunity. He epitomises the institution of Guru-Shishya throughout his achievement years. Such an example needs to be institutionalised and taught as a case study in schools and colleges in India.

- **Navy's Support.** A lesson for the Services. The Navy significantly contributed in shaping Cmde Paulraj's career and achievements. Navy's ability to understand the importance of design and technical talent and nurturing it to prosper was the key to Cmde Paulraj's success. Despite many hiccups about the rules of service (Navy), it made an exception in his case, recognising his extraordinary scientific ability. The Navy harnessed that talent by sending him to the IIT, the UK and later to Stanford. It also overruled his sea time requirement, which would have been mandatory for him to get his promotion. The Navy gave him a double promotion and, recognising his work, recommended him for two distinguished service awards: AVSM and VSM (Ati Vishisht Seva Medal and Vishisht Seva Medal). All the above led to many achievements—the successful rejigging of Sonar Model 170B. The designing and producing APSOH for the Indian Navy: the first indigenously designed and produced new generation Sonar. The indigenous APSOH alone must have saved millions in foreign exchange for the Indian government. Creating of three labs for the DRDO: CAIR, CDAC, and CRL, proved: If you nurture the right talent, it pays manifolds.

- **Respect for Talent.** Admiral Tahiliani's statement (quoted in the text earlier), which he had made when the Navy had to lose Cmde Paulraj for good to Stanford. Navy's loss was Stanford's gain, and he went on to better and more important inventions. However, his exit was because of infighting between the Navy and the DRDO. Too many egos and interference curb the free spirit of innovation and entrepreneurship. The turf wars between government agencies prolonged the LCA project by at least two decades, when Cmde Paulraj was seconded to the DRDO in the LCA project. He left the Navy, and finally, he left the country.

- **Financial Backing.** No project can succeed without finance. The enhanced budget of budget of 280 Lakh INR secured by NPOL director for APSOH from the government was the first step towards the project's success.

- **Future Applications.** APSOH is an indigenous development for the Indian Navy. Its export to foreign navies is under wraps for security reasons. Even after 40 years, the APSOH and its future variants still serve the Indian Naval ships and Submarines. Its design is still secret and a property of the DRDO, Ministry of Defence. The NPOL in Kochi continues its work on the Sonars to produce newer and better versions to meet the Indian Naval Ships requirements.

Vijay Bhatkar: PARAM Supercomputer

In 1988, a young Indian Prime Minister (PM), Mr. Rajiv Gandhi, was on his maiden state visit to the US. He was warmly received and accorded the courtesies reserved for the head of the state of a friendly country by the US Government. However, mere optics do not define the nature of relationships between nations. When our PM asked for a Cray X-MP Supercomputer to improve weather forecasting in India, it met stiff resistance. The bureaucracy in the US government was reluctant to give India a Cray X-MP Supercomputer. They prevailed, and the US government put impossible and humiliating preconditions for the import of a Supercomputer. On return to India, a humiliated prime minister asked the Science and Technology minister, “Can’t we make a Supercomputer in India?”. What followed is a story, of which all Indians would be proud. It is a story charted by Dr Vijay Bhatkar.

Early Influences

Dr Vijay Bhatkar is a product of an indigenous education system. His achievements prove: A man does not need to be educated in foreign universities to accomplish the impossible. He is a shining example of a ‘Made in India” product. His education was homegrown, starting from a humble secondary school in Murtpur, Akola district in Maharashtra. He completed his BTech. from Visvesvaraya Regional College of Engineering (VRCE) in Nagpur and MTech. from Maharaja Sayajirao University of Baroda (MSU) in Electrical Engineering. He completed his PhD from IIT Delhi on a subject in electrical engineering. Computer science, or electronics, was not a subject during his college days. The only subject available was electrical engineering.

In 1972, on completing of his PhD, he was hand-picked up by the Electronics Commission of India (ECI). It had been setup on the lines of the Atomic Commission, and Space Commission had been set up under the guidance of Dr Vikram Sarabhai. He was scouting for the best talent in the country to be part of the Electronics Commission. Its second chairman, MGK Menon, motivated Dr Bhatkar to work with the Electronics Commission, and he stayed with them for eight years, from 1972 to 1980.

In 1980, the Kerala government requested KPP Nambiar, a homegrown scientist, to open an Electronics Corporation in Kerala: KELTRON (Kerala State Electronics Development Corporation). KPP Nambiar had seen Dr Vijay Bhatkar’s work with the ECI and requested him to open an R&D lab for the KELTRON unit in Trivandrum (now Thiruvananthapuram). He moved to Trivandrum from Delhi to open the ER&DC (Electronics Research & Development Centre), one of the biggest labs in India. Dr Bhatkar worked on the development of electronic gadgets and microprocessors at the new facility. On the eve of the Asian Games in 1982, Dr Bhatkar pioneered the colour television broadcast in India. It was done with indigenous technology. Every component of the colour television was designed and manufactured in India. It is a feat which surprised even the South Koreans. The seeds of 'Atmanirbhar Bharat' were sown in the labs of Kerala. He worked with ER&DC till 1987, when his calling came for the Supercomputer.

Param: The Indian Supercomputer

India was primarily an agrarian economy in the 1970s and 80s. However, agriculture in India is dependent on monsoons and the rains. The weather forecasting was in a primitive form as it did not provide the farmers with enough information to act on to optimise their crops. The modelling for weather forecasting is a complex exercise as scores of factors need consideration. Furthermore, as if that is not enough, real-time data from across the world is factored in before obtaining any meaningful weather forecast.

For this reason, India was seeking the services of a Supercomputer. A Supercomputer can handle millions of equations at the same time through a process called parallel processing. This technology was not available to anyone in the world except the US. The 'spin-off' of such technology was in the nuclear, space, and weapons technology applications. The US feared India could misuse the Cray X-MP for defence or nuclear applications. Their control was so strict that even America's close allies and partners did not get access to it.

India was helpless in a paradigm where there was a conflict of interest between India's genuine needs and the US' strategic compulsions. It was forced to develop a Supercomputer of its own through indigenous resources. Dr Vijay Bhatkar was then heading the ER&DC at Trivandrum. In 1988 when Mr. Rajiv Gandhi asked the Science and Technology minister for the state: Shri KR Narayanan, "Why can't we make Supercomputers in India?", he passed the responsibility to Shri KPP Nambiar, who was Secretary of the Electronics Commission, Government of India. Shri Nambiar summoned Dr Vijay Bhatkar, whom he had earlier placed in ER&DC, to take up the challenge. Dr Bhatkar's meeting with the Indian Prime Minister was noteworthy for the questions' frankness and the answers'.

"Can we make a Supercomputer on our own?" asked the PM.

"Yes, we can make it. Although I have not seen one, I have heard of it. And if India can develop its own atomic and space capabilities, we will make a supercomputer too," replied Dr Bhatkar.

"How much time would it take?", asked the PM.
"As much time as we have taken to request the Americans for a Supercomputer and receive

their denial, i.e., three years," replied Dr Bhatkar.

"How much will it cost?", asked the PM.

"Not more than what it would cost us to get one Cray X-MP from the US, including the establishment cost," replied Dr Bhatkar.

The brevity of the enquiry and the answers therein got the approval of the Government of India, and the Supercomputer project was sanctioned. Dr Bhatkar set up the project in Pune. The newly created centre was called C-DAC (Centre for Development of Advanced Computing). Dr Bhatkar, in his wisdom, decided to make the Supercomputer project a homegrown one. He decided to use the parts available in India to assemble a supercomputer. His concept was to procure computing machines readily available in India and to connect them to achieve parallel processing. The system's development was not merely joining the necessary hardware but writing the software for the system applications. E.g., in India, only IIT Mumbai had done some basic work on compilers, which are essential for parallel processing. Writing software for compilers is a difficult task. So, Dr Bhatkar tasked his team to assemble a compiler and write the necessary software.

The journey undertaken by Dr Bhatkar was full of challenges. No one in the team had ever seen a Supercomputer. Thus, training had to start from ground zero. Many research papers on the subject became the base documents for the development of the Indian Supercomputer. The team members attended conferences abroad whenever they had an opportunity to learn the working of a Supercomputer. UK, France, Germany, Russia, and Japan also struggled to develop their own supercomputer but had not reached the computing threshold. Japan was the best, yet a long way from completion. Dr Bhatkar, in his quest to gain knowledge, made many friends in these countries who were happy to be a part of his initiative. In the bargain, he also got access to the UK's modification of a transistor and computer called 'Transputers'. These natural parallel processing components were of great value in the Supercomputer's design. They were procured from the UK in the early stages; later they were made in India.

Why Developing a Supercomputer was so Difficult?

For readers to understand the actual value of Dr Vijay Bhatkar's contribution, it is mandatory to understand the difficulty of assembling a Supercomputer. A Supercomputer is a computing tool that simultaneously processes millions of computations. A supercomputer's processing speed is measured using FLOPS: Floating Point Operations Per Second. For example, one tera FLOP means a trillion floating point calculations in one second. What one teraflop computer can do in a second, a human doing one calculation per second, will take more than 31,688 years. When India's first Supercomputer, Param 8000, was commissioned, it achieved around one giga FLOPs processing speed, much less than today's tera FLOP. However, it meant doing one billion (109) floating calculations per second. Such high-speed calculations meant using a system of parallel processors simultaneously processing part of the same problem. The system integrates all the answers and connects them to its logical end. Such a computer is required for weather forecasting, as already explained. A supercomputer comes with associated problems like high power requirement, and the consequent heat generation. Due to high-power computing speeds, both elements above are in excess and require specialised arrangements to manage them.

The complexity lies in connecting the computer hardware in a parallel loop, writing software for the Supercomputer for the designed configuration to allow the computer to run in parallel, processing bits and pieces of a puzzle, and finally integrating it. Once the basic software is loaded, like the Windows or IOS (I-Phone Operating System) (examples given for understanding), software for the application that will run on it, like weather forecasting, space research, or nuclear reaction, is written. In the configuration of the machine, which runs a particular application to get a near real-time solution, lies the problem's complexity so much that Cray manufacturers declared that the task is so complicated that it cannot be done by anyone other than the experts at Cray.

Dr Vijay Bhatkar defied the experts at Cray, using homegrown technology and engineers. He wrote the entire architecture of the Supercomputer to redefine its parameters and came out with an Indian version which was second only to Cray X-MP. The X-MP, at that time, was a marvel of science. It revolutionised the computing process and solved complex problems. It was a path-breaking invention. Dr Bhatkar has attributed his extraordinary success to his understanding of the Hindu philosophy of Purush and Prakriti: A concept of zero and ones; the binary. He believed that this concept led to the digitisation process. His deeper understanding of Hindu philosophy helped him to apply its principles in designing the Supercomputer.

Since then, the computing speeds have gone a thousand times up. However, it was the Cray X- MP which showed the way. It is an ode to Dr Bhatkar's understanding of computers and belief in his capabilities that he persisted and produced a Supercomputer in less than three years. His first six months were a disaster as the government could not provide him funds. The file on which the sanction was accorded was not traceable. In its absence, the finance ministry refused to fund the project. The Param team of scientists and administrative staff worked without pay for six months. It is a tribute to the trust he had built in his team that none left him and kept working for six months living on their individual savings. Also, there was no purchase of equipment for six months as there was no money. Nevertheless, he could complete this project in the stipulated span of three years.

Validation of the Project

Dr Bhatkar knew that his sceptics would never believe that he had developed a supercomputer. The only way to silence his critics was by showcasing it in a foreign exhibition or a computer fair. So he decided to field a proto-type of Param at the Zurich Supercomputing Conference on Parallel Processing (CONPAR) in 1990. The computer's performance was beyond expectations and stood second in the fair next to the Cray X-MP. So surprised were the media in the US that after the following year's supercomputing fair in Washington DC, the Wall Street Journal wrote, "Denied Supercomputers, an angry India does it". There were other countries like UK and France, Germany, and the Soviet Union, but their machines failed to impress. The first Supercomputer, Param 8000, had a theoretical speed of one giga FLOPS on a 256 nodes basis. However, it was designed for 64 nodes, thus limiting its performance to around 200 mega FLOPS. The Param series of Supercomputers were then developed and have come a long way in their performance and applications. The latest is the Param Sidhi-AI, which has a processing speed of 4.6 peta FLOPS (1015), i.e., a thousand tera FLOPS. Dr Bhatkar had dreamt of an Exa-scale (1018) computer, which the world is now grappling with. He submitted a blueprint for an Exa-scale computer to Science and Technology Commission in 2012, and the then Manmohan Singh government had approved the project in 2014.

The Param computer experiment was a resounding success. Today a complex task can be completed only with a supercomputer. Like, Space, Defence and Nuclear fields are some of the beneficiaries of the computing capabilities of the supercomputer. If India did not have a Supercomputer, India's space programme or nuclear capability would have languished. India's strategic posture would have been threatened vis-à-vis its neighbours, and India would be a third-world nation like its neighbours. The US sanctions in the late 1980s were a blessing in disguise; as Dr Vijay Bhaskar says, "Every Challenge comes with an Opportunity".

Yet he laments the lack of progress in manufacturing computer hardware and processing components in India. He has a special appreciation for the 'Transputer', the fusion of Transistor and computer, done by the British. He believes it was a marvel in parallel processing and proved very useful in making Param.

Honours

For his contribution to enhancing ICT (Integrated Computer Technology) in India, Dr Bhatkar was awarded the Padma Shri and the Padma Bhushan by the Government of India, and Maharashtra Bhushan by the Government of Maharashtra.

Learning from Dr Vijay Bhatkar's journey of Supercomputer

Dr Bhatkar's life journey has been a roller coaster of challenges and achievements. His entire life is a lesson, yet the important ones relevant for this paper are given below.

- **High Achiever.** Dr Vijay Bhatkar is one of the most extraordinary individuals. A man of his abilities would have succeeded in any environment and credit for all his achievements goes first to him and then to anyone else. He is a man in the category of 'Highest Achievers'.

- **Indian Education.** India has many good education institutes that have the ability to nurture the best scientists in the world. To entrust faith and strengthen them is the onus of the government of the day. Dr Bhatkar's entire education was in India, from a secondary school in Murtizapur, Akola district, to PhD, IIT Delhi. He learnt electronics in India and made the Supercomputer based on his knowledge of electronics and computers, which he had acquired in India.

- **Need.** For innovation a 'Need' is a strong motivator. Had the US given the Supercomputer with its customary conditions, the development of Supercomputers would have been a different story. Their denial and our 'Need' compelled us to undertake this critical innovation.

- **Building a Team.** No one in Dr Bhatkar's team, including himself, had seen a Supercomputer. He built his team from scratch. He recruited engineers, some of whom came from the ER&DC centre in Trivandrum, where he was the director, and engineering graduates of Pune University to do a task they had never undertaken. He trained and guided them, allowed them to express their opinion and built a team that delivered a computer earlier than the stipulated time. The lesson of his team building is essential for others to emulate.

- **Leader.** Dr Bhatkar, the leader. The lesson of his leadership is crucial. He was a leader and the one with absolute faith in the outcome of the Project. Many sceptics denounced his optimism. Even some of his team members were discouraged when Cray made a declaration: the writing of software for the Supercomputer is so complex that no one other than scientists at Cray can do it. However, Dr Bhatkar had complete confidence in his abilities. He guided and carried the team to give them the confidence to execute the task. His team had implicit trust in him. When no funds for the team were forthcoming from the government due to some glitch, the team worked without pay but did not leave him.

- **Indigenous Effort.** Dr Bhatkar and his team broke the myth that Indians require foreign assistance for complex scientific tasks. All the engineers were homegrown and had the confidence to execute a task. They worked under conditions of stress and strain to deliver the product. The Param computer was a bottom-to-top indigenous effort.

- **Innovation Culture.** The innovation culture is essential in any community, scientific or otherwise. Dr Bhatkar epitomised that spirit. He had not even seen a Supercomputer when asked to undertake the task. Nevertheless, he was sure of his innovative skills and accepted the challenge. Based on his understanding of mathematics, he designed a new architecture for the Param computer, faster and cheaper than the gold standard, the Cray X-MP machine.

- **Importance of mathematics.** Dr Vijay Bhatkar was an engineering student who dealt more with physics than pure mathematics. However, while doing a PhD, he realised the Importance of understanding mathematics. He studied MTech level maths independently through textbooks and started teaching maths to PhD students. His understanding of maths allowed him to grapple with the nuances of high-power computing (HPC), which was the key to designing a Supercomputer.

- **Focus.** Dr Bhatkar's singular focus on whatever he did was crucial to his success. He was asked to start a colour telecast of the 1982 Asiad events. He led the Project and made it happen. India got for the first time a colour TV Telecast. He was asked to set up the KELTRON lab. He did it and opened 18 factories in Kerala in five years during the left party rule. It is with the same focus that he worked on Supercomputers.

- **Support Indigenous Manufacturing.** Dr Bhatkar believed that to be a true 'Atmanirbhar Bharat', policies must take into consideration the state of local manufacturing and resources available. These policies need to support indigenous manufacturing of high-technology products. One of the lessons that emerged in the case of Param computers, while the team could design the Param, the major processing components came from abroad, like the Microprocessors and Transputer. Developing a hardware industry is a must to achieve a cent per cent indigenous product.

- **Government Support.** In Dr Bhatkar's case, the government support was available from the start as it was the need felt by the Prime Minister. Despite many delays, the project was complete in under three years. This case is an example of how a project can live up to its full potential when government is backing it.

- **Finance.** The government of India provided the finance for the Project. Thirty crore INR was the budget allotted for development of the project. Once the Project was sanctioned on paper, the allocation of money came through fast and on time. In the first six months of the project, there was no money provided due to a bureaucratic hurdle of the government sanction not available on file. This delay meant the project was on a standstill mode for the first six months. The example highlights how money plays a critical role in a high-technology project.

- **Indian Scriptures.** Dr Bhatkar drew inspiration from our old scriptures and knowledge. There are many solutions to modern-day technology problems in ancient Indian writings. Thus for a scientist, the knowledge of Indian scriptures is an X factor in design and development.

- **Future Applications.** The PARAM 8000 series has now given way to many newer versions, with the processing speeds going into Peta Flops. The importance of the PARAM story lies not only in the development of a supercomputer alone but also in taking the technology fight to the originator: CRAY of the USA. In 1998, CRAY established a subsidiary company in Bangalore, India, for future development of the CRAY series of supercomputers and high-power computing. This investment in India was due to the continuous upgrade of the PARAM 8000 series. 1998, India made the PARAM 10000 series of supercomputers, a 100 giga Flop (G Flops) machine. The PARAM series has now reached computing speeds in Peta Flops (1015) with the aspiration to reach the Exo (1018) levels. Technology breaching, which means reaching higher levels of technology, is a good way of attracting better technology and investment in the country.

PART II: Learnings for the Future

The lessons/takeaways are listed at the end of each case study. This sequencing allows the reader to understand the lessons from each case better. The lessons have been assembled under a standard heading in this part. The idea is to reiterate in the reader's mind what we can learn for the future.

Findings

- **Vision:** Vision is a dream of a better future. When the dream is big, its success is sweet and satisfying. Success without a dream is an achievement without struggle. In the case of all four case studies, the men who led them were dreamers who had a dream to achieve something big. Sam Pitroda had the dream of 'Connecting India', and Prof. Mallik dreamed of taking India into outer space and securing it from there. Commodore Paulraj dreamed of giving his parent service, the Indian Navy, a Sonar which would never let another Khukri sink due to an enemy torpedo. Dr Vijay Bhatkar dreamt of giving India a supercomputer for weather forecasting to help the farmer community. For an entrepreneur, dreaming big is the first step towards his achievement. Creating an ecosystem where talented people have a space to dream is essential for a policymaker. Restrictive policies, regulated economies, and education systems stunt dreaming.

- **High Achievers:** All four individuals discussed in the paper shared one common thread. They were and are all 'High Achievers'. This common thread makes them unique and becomes the most vital learning point. To achieve the impossible, one has to have a strong desire to achieve something out of the ordinary.

- **Outstanding Professionals:** The most crucial finding that stands out in all four cases is the presence of a strong personality driving the project. Each individual was competent, possessing outstanding knowledge in their respective fields. In some cases, they pioneered technology unheard of in India. Thus, a knowledgeable person with a clear vision is necessary to drive a project to succeed. To achieve extraordinary results in technology, the leader has to be a master of his subject. His knowledge is the starting point for the team members to emulate. As is evident in the case studies, most team members of the projects learned the concepts and worked from the vision and blueprint drawn by the leader.

- **Leadership:** Each individual who led the project in the case studies we discussed was outstanding. They were all natural leaders and thus drew their followers by the sheer weight of their personalities and commitment to the cause. They all had a desire to innovate something out of the ordinary. In doing so, they became leaders and allowed people to follow them. Their work inspired the leadership. They attracted people because of their knowledge and passion, essential to non-military leadership. In all the cases, they guided their teams from zero knowledge of the project to delivery instruments. In Sam Pitroda's team, no one had seen a digital exchange, let alone manufacture it. In Dr Bhatkar's case, no one, including himself, had seen a supercomputer. In Prof. Mallik's case, the project was so hush-hush that nobody knew of the end state before or during the project. Finally, in Commodore Paulraj's case, no one knew the technology he was using to develop the new Sonar.

- **Cutting-Edge Technology:** Each project discussed dealt with cutting-edge technology of those years. It made the task of achieving success so much more difficult. Understanding the technology involved required people of equivalent calibre and the infrastructure to run it. For example, the supercomputer project was a cutting-edge technology project without knowledge of parallel processing of that high-power computation. For Dr Bhatkar to think of assembling one would have been considered a journey into foolhardiness. It demanded confidence in self-capability and knowledge. Without seeing a supercomputer working, Dr Bhatkar was confident he could design one. He also got a team of engineers who were believers like him to master cutting-edge technology. Moreover, each conquered it for use in India. That is a tribute to the Indian mind for both adaptability and intelligence.

- **Choosing the Workforce:** The biggest challenge for all the projects was recruiting the correct human resources for the execution of the project. In all the cases, without exception, there was no ambiguity about the quality needed for the projects. They knew finding suitable material would be challenging without a dedicated organisational structure. Also, they knew they were not likely to get the best, yet they took the chance to go ahead with the second best. They achieved their goals, signifying our country's large talent pool.

- **Training Methodology:** The recruits were trained on the job in all four projects. They learned the nuances of the technology by trial and error. Patience and belief are the two most important qualities they all received and succeeded. In C-DOT, the team members visited the concerned companies to witness the manufacturing process in the US. In the HPL & DEW case, three Russian scientists were assisting on the job. In the Param Computers, everybody was learning on the job. In APSOH, at the NPOL Cmde Paulraj drove the engineering and design team to learn daily. The projects being of cutting-edge technology, there were no established training norms of books to study. All of it was learned from their leader or on the job through trial and error.

- **Innovation:** Innovation was the key to the success of all four projects. Innovation is a function of intelligent thinking and the application of knowledge. In all four cases, innovations were necessary due to the restrictive regimes that were in place, whether national or international. Either they were direct trade embargoes by the producing nation like the Cray – XMP supercomputer; or there was an embargo on imports of parts like the computer processor 8080 for APSOH; or was the unavailability of a product like the small 128 lines digital exchange to suit the hot and humid climate of India; or the hush-hush secret technology which no one ever talked about in the HPL & DEW case. Innovation was the only way to circumvent these restrictions, which inhibited product manufacturing—innovating small components to suit the local conditions for which out-of-the-box thinking was required; even recruitment or mass production of equipment required out-of-the-box thinking. The use of slower ruggedised microprocessors in the digital exchange, or the use of Slice bits to convert it into microprocessors best suited for hot climatic conditions, was Innovation.

- **Out-of-the Box Thinking:** For 'Out-of-the-box thinking', smart use of the brain function is essential, and Indians have it in plenty. Working in a restrictive environment, how to fill the gaps is well endowed with Indians and in colloquial language, it is called: 'Jugaad'. However, Jugaad had taken up an entirely different meaning. In all cases studied, the projects undertaken were besieged with restrictions and sanction regimes. The use of 'Transputers' in Supercomputers for parallel processing is a classic case of out-of-the-box thinking. The procurement of transputers was possible because of the personal involvement and friendship that Dr Bhatkar had developed with some of the people in the UK scientific community. While the UK, which was trying to develop a supercomputer, had Transputers in their inventory, yet could not use them effectively, as Dr Bhatkar and his team did.

- **Management Style:** All four case studies have shown that the management style practised within them was horizontal. All of it was participative, which encouraged differing opinions and debates whenever confronted with problems, or a decision dilemma. The leaders were open to criticism and suggestions. It thus proves that a horizontal management style in high-achieving projects would yield the best and fastest results.

- **Bureaucratic Impediments:** In all the projects, a common thread which cut across was the role of the bureaucracy in the lack of acceptance or encouragement for the projects. Bureaucracy is averse to change or anything new, as inherent risks involve accepting new ways. Another facet was the influence of foreign agencies called 'Vendors' in today's parlance. The vendors are representatives of big multinational companies who were in those days chief suppliers for all communications, electronic and computer-related products. This dependence was natural, as no meaningful domestic industry could supply these goods. Thus, all ministries depended on foreign vendors to supply state-of-the-art machinery or equipment. Supporting the domestic industry or buying an indigenous product came at the cost of a contract with a foreign firm. It was natural that a foreign multinational with deep pockets was willing to go to any extent not to lose a lucrative contract with the government. Foreign companies wanted to eliminate their competition, therefore they would create impediments in every manner possible for domestic industry to ensure their failure. If the bureaucracy fell prey to such practices, it was because they were risk-averse and preferred an easier way.

- **Government Support:** All four projects were government-sponsored, as they were either in the public interest or in the interest of national security. Despite being sanctioned by the government, each had met with internal resistance. The C-DOT came under heavy criticism from its parent ministry, the Ministry of Telecom, and other associated ministries. The Ministry of Telecom refused to accept the finished product of C-DOT, asking it to come via an open competitive route. Dr Bhatkar's supercomputer project suffered from a lack of funding for the first six months because the 'Government Sanction' file went missing. Commodore Paulraj's APSOH got stuck in a bureaucratic tangle between the Navy, DRDO and the production agency BEL. It is hard to imagine if any private enterprise would succeed in a venture that does not have ab initio government support.

- **Indian Education System:** All the men involved except Sam Pitroda were homegrown scientists and engineers. They were products of regional engineering colleges and the IITs. Even Sam Pitroda had his postgraduate education in India. He did another post-graduation in the US. The relevant education curriculum allowed many engineers to be recruited and tasked with designing these unique projects that the paper brought to the fore. In it also emerged many facets embedded in their core Indian values and their use in scientific work—for example, the Guru-Shishya relationship of Commodore Paulraj with his IIT guide and mentor, Prof. Indrasen. There is a belief in ancient Indian philosophical and spiritual knowledge to find solutions in scientific thinking, as in the case of Dr Bhatkar when he designed a new architecture for the supercomputers by leaning into spirituality. The research work in IIT Delhi by Commodore Paulraj was the basis on which the NPOL developed the most advanced Sonar. Prof. Mallik, a man who was dealing with the most complex of technologies, the High-Density Lasers, learnt all the scientific arguments working for Indian institutions like the DRDO (Defence Research and Development Organisation). Yet it would not be out of place to suggest that while Indian institutes are good, there are not many in number and there is far too less emphasis given in studying cutting-edge technologies.

Infrastructure:

- The infrastructure for research and development was one of the weak links in these stories. At least three projects had to work out of ad hoc structures to house their development activities. Sam Pitroda's C-DOT team worked out of a government-owned five-star hotel in New Delhi. Prof. Mallik had to work out of a makeshift lab: Metcalfe House in Delhi. Dr Vijay

Bhatkar's team was working out of a dilapidated building at Pune University till the new C-DAC was constructed. Only Commodore Paulraj had his team working in a known place like the IIT Delhi and the NPOL in Kochi. The point that needs to be understood is that lack of infrastructure dampens Innovation. It is a tribute to the four men and their commitment; hence, the type of place did not matter to them. Scientific discoveries require equipment and space for experimenting.

- **Finance:** The common thread across all four projects is Government Finance; however, the relative ease of getting finance led to the success of these projects. The GOI needs compliments for recognising and sponsoring these projects. Without the massive government finance, these projects would be non-starters. There may have been hiccups, but the government-sponsored projects helped clear foreign exchange-related transactions without great rancour or fuss. So much so that the budget for C-DOT was allotted in US dollars. It was reflected in the early completion of all the projects. Completing a project like building a supercomputer in less than three years is unbelievable. However, the government involvement in providing finance for parts like the 'Transputers' from the UK helped matters. The corollary is that no serious scientific work can be done in the private sector, where the bulk of the talent pool lies. Most innovations abroad come out through corporate initiatives. They get governmental support, but the initiative comes from corporates or industrial houses. While this is becoming a reality in India today, it did not exist back then. Also, the efforts today are very far and few. The table below gives the type of project budget support the GOI provided.

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Project	Outlay
C-DOT by Sam Pitroda	36 Million Dollars (US) (Equivalent INR in 1987 exchange rate: 46.8 Crore
HPL-DEW by Prof. Mallik	300 Crore (INR)
APSOH by Cmde Paulraj	2.8 Crore (INR)
Param Supercomputer by Dr Bhatkar	30 Crore (INR)

- **Future Applications.** The case studies studied belong to the eighties and the nineties era. In 2023, there has been a sea change in technology, government structures, and processes. We are in a globalised world where national borders have given way to international cooperation. Where countries set up bases irrespective of national boundaries, where technology is shared, and innovations are not patented by a single country. This reality makes the lessons learnt from the last century hard to implement. Either their implementation is complete due to the natural progression of thought and policies or because they have become redundant. However, the principal value of the lessons cannot be thrown away. They remain in spirit and essence similar. For example, the value of leadership cannot be undermined, irrespective of time. The value of Innovation cannot be toned down. While technology changes, using the latest technology bears better fruit, which cannot be denied. Considering the above, the findings at the end of each case for their respective 'Future Application' hold merit. PARAM can be a leading example of leveraging knowledge and resource potential to garner better investment and technology from outside the country to build better products.

PART III: Recommendations

To make India ‘Atmanirbhar’, we must understand our abilities. A lack of vision or confidence often results in a lack of effort to indulge in the ‘Make in India’ initiative. The four case studies have shown that there is no limit to what a human can achieve if he/she has the desire. Having analysed the findings, making recommendations for policymakers, Industry, and future entrepreneurs would be prudent. The recommendations are based on the experiences narrated by the case study stakeholders and are necessarily only derivates of the findings. It would be necessary to mention that the recommendations made might already be in practice by the government. However, it does not mean they need not be heeded. Instead, it means greater stress be laid on them as they have fetched results, as seen through these four case studies. Also, the case study belongs to the periods of 1975 to 2000. A lot has changed in the country since then. India has made rapid development in all spheres. Many new innovative projects have been commissioned and completed. The highway network is one such example. The world, too, has moved ahead, and to keep pace with how the world is changing, the policy changes must cope. These recommendations will thus remain ever helpful.

For Industry and Entrepreneurs

The recommendations below are for the Industry and the future entrepreneurs who wish to make it big, like the personalities in the case studies. These recommendations flow from the actions of the named people and are not difficult to spell but extremely hard to emulate.

- **Private Participation:** India is at the cusp of breaking out of its technological cocoon and leaping big into the future. The signs are already evident, and the recent G-20 has showcased India’s prowess adequately. Yet we are in the big league of Fortune 500 companies. Any cutting-edge innovation, which is a disruption and not a simple innovation, requires private initiative. The government is a provider; it is not an innovator. Hence, private participation in India in cutting-edge technologies has to grow. For it to happen, two things must happen. First, a product need must be identified, and second, the government must find enough reasons to participate. Government participates best if there is a reciprocal payoff.

- **Dream Big:** Dream, and dream big. Unless there is a dream, great height cannot be achieved.

- **Competent Leadership:** Path-breaking projects require visionary leaders who are on top of their professional competence and can guide their teams. They are passionate about what they do and fiercely desire to succeed. They battle odds, be it natural or man-made. They lead by example and set personal standards which are hard to achieve. They are team players and carry the team with them.

- **Out-of-the-Box Thinkers:** All the cases studied bring out the need to think out of the box to solve problems with no straight-jacket solution. Using out-of-the-box thinking and innovating with what is available is the only answer. While dealing with cutting-edge technologies, external support will always come at a heavy cost to the nation or the individual, i.e., if it comes. For the individual, it will usually be in monetary terms, but for the nation, the cost often compromises its strategic national interests. Hence, out-of-the-box thinking and Innovation are essential tools of a toolbox when dealing with high-technology projects.

- **Selection and Training:** Once an entrepreneur undertakes a cutting-edge technological project, he will face a million problems, especially if he only uses homegrown technology and human resources. One of the principal problems he would confront is to make a team which will work on the project. The team's selection and training is the most challenging part of the job. As the leader, he must have the technical knowledge to know what talent is required and what training to impart to them. Training to design the product and then use it will be the leader's function, as no teachers will be available. Training the team is the most challenging part, and a leader must be capable of doing it.

- **Management Style:** All four cases undertaken displayed a horizontal management style. The deduction is that in high-achieving projects where knowledge is limited and Innovation is the key, a horizontal management style would suit the best for quick and desired results. Government policymakers would do well to keep this in mind and not opt for the traditional vertical organisation model for future projects.

- **Manage the Environment:** It is human to feel jealous, and jealousy can lead to actions which are detrimental to positive outcomes. When high-end projects are involved, they evoke different responses in the people around them. Not all will be happy. To succeed, managing of the environment is essential. To appeal for political support may seem the easiest option, but it is not easy nor likely for everyone. Thus, being transparent and explaining the benefits is the best option. Create a win-win for everyone for smooth sailing of the project.

- **Funding:** The funds for innovating high-end technology are always critical in decision-making. Does a private industry get its ROI (Return on Investment) if it invests in the project? For many years, India's defence industry suffered from the same syndrome. Finally, due to friendly government policies, the defence sector has seen movement in manufacturing weapon systems. Currently, at least a dozen defence manufacturers are actively involved in domestic and international trade.

For Policymakers

- **Strategic Policy Document:** It would be impossible for any government agency to make a policy without being previewed to correct, timely, and without relevant inputs. The policy-making body, which is the executive branch of the government, is deep into a myriad of day-to-day administrative and governance issues. It would do them good if they had a policy document which could lay down the strategy the government of the day wants to follow for dealing with 'Innovations and Cutting-Edge Technology'. It could involve a committee which looks at the cutting-edge technologies across the world and how they fit into the Indian ecosystem. A step-by-step approach is the best way forward. Forming a committee to study these on a case-by-case basis could be the beginning. On identification of the relevant technologies, identifying knowledgeable entrepreneurs who are willing to embrace it could be the next step. A time-bound vision and goalpost could be part of the third step in which the share of funding by the government would be the critical component. Finally, trial and acceptance could be the last stage. Such committees could be researching many fields under the government umbrella. Such governmental efforts with the private sector could become the origins of cutting-edge technological innovations for the country. If such a body exists, it should get more impetus and private participation for India to gain greater self-reliance.

- **Vision:** How are visionaries built? Vision is specific to individuals, and it cannot be built. However, one can encourage dreaming. Dreaming big should be encouraged as a part of the school curriculum or routine work. Make it a habit. And some dreams will come true. Schools are the harbingers for making dreams. If our children can dream big and tender ages, they will create magnificent products when they come of age. Introduce vision-building in the school curriculum.

- **Build a culture of science and technology:** All the projects done were in core science subjects. Inventions are science-oriented, leading to modifications for the product's betterment. While India has progressed in increasing educational institutes, most are not adding value. Science must have adequate incentives in policy for aspiring students to opt for it. Laboratory facilities in rural areas and good teachers are essential to bring science and tech to our daily thought process. In the case studies, it was brought out that all four projects had enough homegrown engineers to carry them forward. Nevertheless, four projects in one decade seem less for a country as large as India.

- **Create Infrastructure:** High-Technology projects like the one studied above require infrastructure to house their teams and equipment. The infrastructure required is both power intensive and requires a controlled environment. Such a facility would not be cheap. It would boost Innovation if the government could create infrastructure for research teams working on cutting-edge technology projects at low costs. Creating such infrastructure has to be evenly spread geographically in all states so every student has a facility nearby. Special budget provisions could be necessary under a minor head of the budget for such a facility in every state.

- **Talent Spotting:** How does a nation spot a young talent who could get a Nobel prize someday? A challenging task. No magic machine could pick out an individual from a group of boys or girls. Similarly, amongst grown-ups, there is no such mechanism. However, at every stage, there are indications of bright sparks in individuals, similar to what Professor Indrasen spotted in Cmde Paulraj and what MGK Menon of ECI spotted in Dr Vijay Bhatkar. It would be thus prudent for policymakers to enhance the scope of talent-hunting teams and their reach. Select ten, and one will emerge as the winner; but if 100 are selected, ten will come out as winners. India's 'B' class and 'C' class cities are growing, with incredible talent wanting to come out. Inhibited by language, they are shy of emerging from the shadows. Recent government initiative to teach degree courses like medicine and engineering in regional languages is a step in the right direction.

- **Recruitment Avenues:** In all the case studies, the project leaders found it difficult to recruit the appropriate human resources for their projects, as no institutional mechanism or agency for recruitment was available. While instituting such an agency may be complex, priority or strategic projects should have access to a centralised database. In the present day, such a system is possible. A central statistical organisation or the human resource development ministry could hold records of all outstanding candidates passing out of known government and private institutions, with their contact details.

- **Private Sector Participation:** Encourage private sector participation in national developmental goals. Defence and space technology are the niche areas where only the government can carry out research, as it is expensive and does not have commensurate commercial spinoffs. The government should partner with and encourage the private sector to enter fields like space. The defence sector in India has opened up as a part of the 'Make in India' initiative. Similarly, other strategic fields should also open up. More people will lead to more Innovation.

- **Government Support:** While the above recommendations speak of the private sector participation, the principal role will have to be played by the government. In all four cases, it was a common factor, and it is evident that they could not have survived without government support. Moreover, if possible, when a Prime Minister gets involved, the scheme gets a tacit nod to move on the fast track, as it happened with C-DOT and the Param Computers. If the government actively supports Innovation, it would attract more volunteers to come and do innovative work. Government support should be active and transparent for all to know, and if it draws attention, the chances of getting better talent increase.

- **Government Interference:** While government support is necessary for Innovation and provides much-needed oxygen, government interference kills it. Avoid government interference in science and technology. The Cmde Paulraj case study aptly brings out the example of the LCA. He had worked out a time plan of six years for the LCA programme to fructify. Untimely governmental interference extended it to 30 years, a fivefold increase in time and cost.

- **Rural First as a Strategy:** 70% of India's population lives in villages and towns. If India's transition to better living conditions and happiness has to grow, it must start from villages. The C-DOT scheme was so successful because it started with villages first. It has the largest landmass and the population to back it. The government should encourage schemes coming out in towns and villages. There are incentives, yet villages have not joined the new revolution.

- **Future Acquisitions:** In the findings under the heading 'Future Applications', an observation is listed which accepts a dilution in the applicability of the 'Findings' in the current day due to the time gap between when the cases studied were implemented and the present day. Much has changed since then, like technology, the government policy framework and the globalisation of R&D. Pure indigenous equipment production is unheard of today as it impinges on sound economics. Every nation cannot produce everything. It is about finding a competitive advantage over another. In the periods studied in the case studies, India was a closed economy on the verge of opening up. Today, India is an open, well-integrated liberalised economy. India will have access to cutting-edge technology available abroad if it can afford to pay the price. In niche areas where technology is denied, it has to find ways and means to develop it. That is where policy challenges lie. In governmental procurement procedures, the existing categories are a variant of either 'Make' or 'Buy' in Capital Acquisition schemes. As per the new DAP (Defence Acquisition Process) 2020, there are variants of the above. These are broadly classified as 'Buy', 'Buy and Make', 'Leasing', 'Make', 'Design and Development (D & D)' and Strategic Partnership Model. All the above have a component of make in India except the first category: 'Buy'. However, despite the good intentions, they fail to get us the best product. What can change? A recommended line of action is described below.

    - **In the 'Buy' category, add the Suffix: 'and Make Better'.** This qualification means buying from an outside source, buying the technology, and studying and learning the technology to innovate it to make a better technological product. This practice exists in countries that thrive on Innovation, e.g., Japan, China and South Korea. Such an addition to DAP with the necessary qualifications would change the concept of buying. In the long term, the company which sells the technology would be compelled to collaborate due to a price advantage that would accrue to both parties.

- Another alternative to the above could be a reverse, i.e., **'Make to Buy Better'.** This category envisages that the domestic industry produces a product or system close to what is the best existing in the world. Once the technology being used is close to the 'Cutting-edge Technology' available, it would give our country a superior position to negotiate the contract for a purchase. A denial would mean India would give a shot at cracking at best. Such a fear will force the competitor to weigh the options very carefully. This pattern was witnessed in the Param computers development process. CRAY denied India the X-MP version, which led to India making the PARAM 8000, which was second only to CRAY at the Zurich supercomputing fair in 1990. In 1998, C-DAC made an improved version of PARAM 10000, which had processing speeds of 100 giga Flops. This development led CRAY to set up a subsidiary company in Bangalore, India, to join the race for high-powered computing. This category would lead to the birth of a new category, 'Making it Together', when the foreign company collaborates with its Indian counterpart to make a new product as an equal stakeholder. This new category would fit into the country's long-term goal of 'Atmanirbharta', i.e., Self-Reliant and Self-Sufficient, and clever sharing of technology needs with the rest of the world.

The recommendations in this part are a mix of what has emerged from the case studies and the application of knowledge to crystal gaze at India's future requirements. Each of them can be a subject of further debate and discussion depending upon their degree of merit.

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