MIDDLESEX UNIVERSITY BUSINESS SCHOOL LONDON

MIDDLESEX UNIVERSITY

DISCUSSION PAPER SERIES:

ECONOMICS

TECHNOLOGY ACCUMULATION IN INDIA'S SPACE PROGRAMME GROUND SYSTEMS: THE CONTRIBUTION OF FOREIGN AND INDIGENOUS INPUTS

A BASKARAN

No 93
DECEMBER 2000

Middlesex University Business School
The Burroughs, Hendon, London, NW4 4BT

Technology Accumulation in India's Space Programme Ground Systems: The Contribution of Foreign and Indigenous Inputs

A. Baskaran

Middlesex University Business School, The Burroughs, Hendon, London NW4 4BT.

Tel: 0181-362 5732, Fax: 0181-362 5981, *e-mail*: A.T.Baskaran@mdx.ac.uk

Abstract

Since the late 1960s, India appears to have accumulated a high level of technological capabilities in the area of ground systems in India's space programme. This paper analyses the process of technological learning and focuses on the role of international collaboration, foreign imports and indigenous efforts in building capabilities in different areas of ground systems technology such as rocket launching systems, satellite control and tracking systems, and earth stations during this process. This paper illustrates the importance of foreign technological inputs, particularly in the formative phase, for competence building in a developing country like India. It also demonstrates that strong indigenous efforts along with foreign imports were necessary for India to achieve threshold capability and sustain technological change in the accumulative phase. It appears that both foreign imports and indigenous efforts have played a complementary role in competence building in ground systems technology in India.

Keywords: Technological learning; Technological accumulation; Competence building; Indian space programme; Ground systems; Earth stations; Spacecraft control systems; Rocket launching stations, Technological imports; Indigenous R&D

1. Introduction

Since early 1980s, there have been a good number of writings on the process of technological learning in the developing countries. Particularly, the interest has grown when countries such as South Korea and Taiwan in South East Asia witnessed rapid industrialisation since the late 1970s (e.g. Bell and Scott-Kemmis, 1985; Westphal et al., 1985; Kim, 1987, 1993, 1996; Lall, 1987, 1990; Katz, 1987; Enos, 1991; Enos and Park, 1988; Bell and Pavitt, 1993, and Hobday, 1995, Zao, 1995; Okejiri, 2000). The experience of these countries showed the importance of imported inputs, particularly during the initial period, in the process of technology accumulation. At the same time, they also showed the importance of local knowledge to assimilate, absorb and improve the foreign technology. India's experience in competence building in ground systems technology suggests that developing countries need significant foreign inputs particularly during the formative phase first to build threshold capabilities and then to keep pace with technological change. It appears that without significant foreign inputs at the formative phase and some form of imported inputs at later phases, developing countries are unlikely to succeed in building capabilities even in relatively less complex systems such as ground systems technology.

For a successful space programme, capabilities to build both the space and ground systems are equally important. Also, they are mutually dependent. Due to the higher visibility and the attraction of the satellites and rockets, one tends to forget the large network of ground systems that supports them. Building and launching satellites, maintaining them in orbit and utilising them will not be possible without the support of appropriate ground systems. Therefore, developing capabilities in ground systems in a space programme is considered very important. Although ground systems technology is relatively less complex than the rockets and satellites, with the space systems becoming more and more complex, the ground systems also have become more advanced and sophisticated. This made competence building more demanding and it will be interesting to see how India, a second-tier newly industrialising country in the developing world, has accumulated a high level of capabilities in this technology.

The ground systems technology can be identified into three different categories: rocket launching facilities, spacecraft control and tracking facilities, and spacecraft utilisation facilities (communications, remote sensing and meteorological). In India, the first two are directly under the control of Indian Space Research Organisation (ISRO), and the last one is under the joint control of ISRO and various user agencies (see Figure 1). Ground systems technology was the first area to witness major indigenous effort in India's space programme, as it was relatively less complex and the industry was more confident of meeting demands in this area rather than more complex areas such as rockets and satellites. Initially, India utilised the opportunities offered by international co-operation, to lay the foundation. Then, it appears to have judiciously combined foreign and indigenous inputs to build threshold capabilities. Subsequently, it started putting more emphasis on complete indigenisation, that is self-reliance. By the late 1990s it appears that the Indian industry has acquired, with the help of ISRO, capabilities to design and fabricate nearly all types of ground systems needed for the space programme, with the minimum possible imported inputs.

This paper mainly analyses how this capability was acquired. Particularly, it focuses on the contribution made by foreign collaboration, foreign imports and indigenous efforts towards competence building in ground systems.

2. Development of rocket launching systems

India has established three rocket launching ranges and a network of satellite tracking/control stations under the space programme (see Figure 2). In the 1960s, it set up the Thumba Equatorial Launching Station (TERLS). For this, India was helped by foreign collaborations. In the 1970s, it established Sriharikota Range (SHAR) and the Balasore Rocket Launching Range (BRLR). To build these stations, it appears that India followed a policy of developing locally whatever systems it was capable of at the time and of importing the rest.

2.1. Thumba equatorial launching station (TERLS)

Following an agreement between the Department of Atomic Energy (DAE) of India and the National Aeronautics and Space Administration (NASA) of the US to carry out certain scientific experiments using sounding rockets, TERLS was set up near Trivandrum in 1962. Soon after, the United Nations (UN) recommended that sounding rocket launching facilities should be established at the magnetic equator to conduct scientific experiments. Until TERLS was established, there was no ground facility anywhere in the world to launch rockets into the magnetic equator. India seized this opportunity and offered TERLS to the UN for use as an international facility. In 1965, the United Nations General Assembly accordedd sponsorship to TERLS, without funding (DAE, 1965-66:49). Nevertheless, scientists from different countries started conducting scientific experiments using their own sounding rockets and equipment. Some of them donated some equipment to India to help launch operations. The French space agency, CNES, donated some ground equipment, including Cotal Radar with a range of about 300-km, for tracking the actual trajectory of rockets. The former Soviet Union provided a Minsk-II computer for the analysis of data obtained from M-100 meteorological rockets. It also provided a radar tracking station. NASA provided a tone ranging system (DAE, 1966-67:65; 1970-71:143).

However, large number of the items needed for the ground systems came from local sources. From the late 1960s, the scientists and engineers at TERLS started indigenous development of various items. During 1968-69, they designed and developed a Universal Launcher for Nike-Apache and Centaure rockets. Subsequently, they also developed launchers for the British Skua and Russian M-100 rockets, a VHF ground telemetry receiving station and an S-band surveillance radar (DAE, 1968-69:68-69; 1970-71:143). Further, capabilities to launch different rockets such as Petral, Booster Arcas, Dragon, Judi Dart and Rohini series (including 560 mm diameter rockets) and a number of facilities such as Pulse code modulation (PCM) telemetry station, digital data system for COTAL radar, FM/FM telemetry station, pay load integration facility were built progressively (DOS, 1974-75:21; 1978-79:27). By the mid-1980s, an advanced S-band TTC system was established

(DOS, 1975-76:24; 1985-86:45). It appears that all these systems were built by employing a combination of foreign imports and local inputs.

2.2. Sriharikota range (SHAR)

By the late 1960s, ISRO realised that it needed a station on the East Coast of India for launching satellites. The scientists studied all the major launch sites in the world including those of the US, Japan and the wartime sites in Germany and selected the Sriharikota Island in Andhra Pradesh for the new range (DAE, 1969-70:70). Sriharikota Range (SHAR) was built keeping in mind the future needs of the space programme. It was built in three phases. In the first phase, a sounding rocket launching pad for 300 mm and 560 mm diameter rockets, a vehicle preparation facility and an instrumentation facility for housing ground support telemetry and tracking equipment were installed. The launcher and the telemetry and tone ranging systems were developed at TERLS. On completion of the first phase, SHAR was commissioned in October 1971. In the second phase, other ground support systems for range operations to carryout ground and flight tests of indigenous rockets, and tracking were established. In the third phase, the ground systems needed to launch the satellites were built. SHAR also included facilities such as Solid Propellant Booster Plant (SPROB) to produce large size propellant grains for the satellite launch vehicles; a Static Test and Evaluation Complex (STEX) for static tests and simulated high altitude tests of large rocket systems; a Rocket Sled Facility; and a high speed rail track and rocket powered trolley facility for dynamic testing of rocket sub-systems. These facilities were built by employing significant number of imported equipment. They were created during the SLV-3 project, the first satellite launch vehicle built by India. Subsequently, they were expanded for Augmented satellite launch vehicle (ASLV) and Polar satellite launch vehicle (PSLV) projects. The electronics sub-systems needed for PSLV launch complex, equipment needed for the liquid propulsion stage related services and facilities were imported (DOSa, 1988-89:55). While building SHAR, India appears to have followed a policy of importing only those equipment, which it was not capable of producing locally. ISRO involved the industry and other public R&D organisations to develop locally most of the equipment it required for building SHAR.

In the area of telemetry systems, an FM/FM telemetry system was established in 1971. The sub-systems for this were developed at TERLS. Subsequebtly, a satellite telemetry station and satellite launch vehicle (SLV) telemetry station were installed (DOSa, 1973-74:26-27). Initially, the PCM telemetry equipment was imported. Then, the Space Science and Technology Centre (ISRO), Trivandrum, developed a similar system indigenously. Subsequently, the telemetry system was converted using indigenous R&D to operate in S-band.

In the area of tracking, one of the important systems established at Sriharikota Launch Complex (SLC) was the radar system that included acquisition radar, tracking radar and long-range radar. The French space agency CNES donated Cotal radar (DOSa, 1974-75:24). The acquisition and tracking radars were developed at Vikram Sarabhai Space Centre (VSSC), Trivandrum. Some national laboratories such as the Babha Atomic Research Centre (BARC), Tata Institute of Fundamental Research (TIFR) and the Space Applications Centre (SAC) of ISRO had developed various sub-systems for them (DOSa, 1973-74:27). A C-band radar with a tracking capability up to 2, 500 Km was developed at VSSC along with a C-band transponder (for SLV-3 rocket) to operate with this radar (DOSa, 1975-76:18). During 1979-80, another identical C-band radar was installed at the range. Later, these facilities were augmented for S-band operations. Three long range precision tracking radar systems and a Precision Coherent Monopulse C-band (PCMC) radar were developed by the Bharat Electronics at Bangalore, with the help of ISRO for PSLV operations. However, all the critical sub-systems appear to have been imported (DOSb, 1984-85:41).

SHAR Computer Facilities (SCOF) was established by imported computer systems to provide computing and processing support for rocket launches and satellite operations. This included one TDC-16 to provide real time trajectory data for the existing tracking system, an IRIS 55 for SLV-3 missions, a TDC-316-I for external stations like the down range station at Car Nicobar, and the TDC-316-II to support the *Bhaskara* satellite (DOSb, 1980-81:56; DOSa, 1979-80:27). In 1983, the first 32-bit computer indigenously made by Electronic Corporation of India Limited, Hyderabad, was added to the facility (DOS, 1982-83:25). Further, a multi satellite support system employing Micro-78 and TDC-316 computers were also developed locally (DOSb, 1983-84:35). The design and development of the ISRO computer networking system for interconnecting computers at various centres were carried out under the ISRO-DFVLR (the German Space Research Organisation) programme (DOSb, 1984-85:42). The telecommand system for the operation of *Aryabhata* satellite was designed and developed indigenously. Then to support the SLV-3 launch, another telecommand system was developed by VSSC. Subsequently, all these facilities were improved and expanded for the ASLV and PSLV projects, by employing both the local and imported equipment. In the 1990s, ISRO initiated an indigenous plan for developing high value items such as multifunction receiver and Range and Range Rate system (DOSb, 1997-98:56).

2.3. Balasore range

In 1978, the Balasore range in Orissa was specially established to launch meteorological sounding rockets for the Monsoon Experiment (MONEX). This was part of the Global Atmospheric Research Programme (GARP) which was jointly conducted by the World Meteorological Organisation and the International Council of Scientific Unions (DOSa, 1978-79:11). It appears that the industry and ISRO have developed most of the equipment for the range, except some critical subsystems and components.

3. Development of satellite control and tracking systems

Five network stations located at Sriharikota (SHAR I and II), Ahmedabad, Car Nicobar, Trivandrum and Kavalur form the ISRO Telemetry, Tracking and Command Network (ISTRAC). This network provides ground support for tracking, data acquisition and spacecraft control operations. This gives TTC support for all satellite launch vehicle missions of ISRO and to the satellites launched by India and other countries (DOSb, 1990-91:73). These stations were commissioned between 1975 and 1979 employing both imported and locally made equipment and sub-systems.

During 1975-76, a satellite control centre was set up at TERLS for commanding and receiving telemetry data from satellites crossing Thumba region. The SHAR ground station was commissioned in 1975 to track *Aryabhata* and it was then augmented to support *Bhaskara-I* and *II*, *APPLE* satellites and SLV-3 (DOSa, 1978-79:27). The Ahmedabad ground station was identical to the station set up at SHAR in 1979 for data acquisition and to provide tracking support for *Bhaskara-I* and *II*. The Down Range Station (DRSN) at Car Nicobar Island was set up in 1979 for SLV-3 project. ISRO centres have developed various sub-systems needed for the station (DOSb, 1979-80:59).

In 1977, the Satellite tracking and ranging station (STARS) was set up at Kavalur with the help of the Soviet Union. It was used for optical tracking, laser ranging, photographing and precision tracking of satellites belonged to different countries in the geo-stationary and low earth orbit over the Indian Ocean (DOSb, 1980-81:53). The Soviet Union and the Inter-Cosmos participants -- Czechoslovakia, Hungary, Poland and the German Democratic Republic, provided the tracking camera, laser equipment and the accessories of the station. The Soviet Union also provided computer programmes for processing laser and camera observations (DOSb, 1976-77:43). ISRO supplied the necessary supplementary equipment as well as the observatory and laboratories for the station and installed all the equipment (Patriot, 25 January 1977). Various foreign space agencies provided assistance to set up spacecraft control systems, as ISRO participated in international scientific projects such as the MERIT programme, a joint campaign of NASA, CNES, ISRO and Inter-Cosmos to determine the variations in the rotation of earth (DOSb, 1981-82:40).

When India bought the first generation Indian national satellites, INSAT-1s, from the US, ISRO decided to establish an exclusive facility, the Master Control Facility (MCF), for them at Hassan. In 1978, ISRO started the indigenous development of a number of systems including a 14m antenna, no-break power supply system, ground communication equipment and various other elements related to the integration and checkout of the tracking and telecommand (TTC) earth stations (DOSb, 1982-83:42). In 1982, the MCF was established that consisted of two independent satellite control earth stations and a satellite control centre. Most of the equipment for the earth stations such as electronics systems, 14-metre diameter fully steerable antenna systems and the standby power system, were indigenously developed. The equipment for the Satellite Control Centre (SCC) was supplied and installed by the Ford Aerospace and Communications Corporation, the US (*Times of India*, 17 August 1983; DOSa, 1982-83:10). To expand and modify the MCF for the second-generation INSAT-2 satellites, the industry supplied an 11m-diameter antenna, C-band equipment and the tracking receiver on a turnkey basis (DOSa, 1993-94:28).

4. Technology development in Earth stations

Competence building in earth station technology for satellite communications and remote sensing has started from the late 1960s and late 1970s respectively. This process started with foreign collaboration or foreign imports and went through stages of indigenous efforts to reduce imports. Figure 3 and Figure 4 illuminate this process.

4.1. Ahmedabad and Arvi stations for satellite communications

At first, in 1967 the Experimental Satellite Communication Earth Station (ESCES) was set up in Ahmedabad with assistance from the United Nations Special Fund. The International Telecommunication Union (ITU) prepared and executed the project. The Nippon Electric Company (NEC) of Japan supplied the equipment (Pant, 1992:8). A nucleus of personnel for the station was trained in Japan and in the US with ITU fellowships. The main objective of setting up ESCES was to train Indian and foreign engineers in satellite communication techniques, besides conducting experiments, using NASA's ATS-2 communication satellite. At the time, many countries started acquiring earth stations and needed trained personnel to operate them. Hence, the UN was involved in setting up an experimental station to provide such training. For this purpose, a College of Satellite Communications Technology was attached to the station and started providing training "with the assistance of two UN experts" (DAE, 1968-69:71). This helped to create within three years "a hard-core of trained personnel" in India, which "was used for establishing satellite communications on a commercial basis in India" (Rao, 1992:6).

By the early 1970s, ISRO planned to conduct the Satellite Instructional Television Experiment (SITE), using a NASA satellite. For this, the station at Ahmedabad (AES) was expanded between 1971 and 1976, again with financial and technical assistance from the United Nations Development Programme (UNDP) and ITU. The principal objective of the ITU/UNDP project "was to transfer as much technical know-how as possible so that equipment could be designed and built locally" (Nickelson, 1992:5). ISRO developed the equipment for the expansion of the station indigenously, importing only components and hardware not available locally. The earth station up-link chains were produced employing local design team. Consultants from the British Aircraft Corporation and Hughes Aircraft Company (USA) were brought in by ITU to assist the team. They helped in developing the prototypes and all of the essential elements of the up-link earth station including the feed systems, amplifiers, converters and modulators (DAE, 1970-71:149). Further, the project helped to import the required test equipment and components that were not available in India. It also established the Test and Calibration Laboratory at Ahmedabad which "provided an invaluable resource that was indispensable in the subsequent development of space-qualified hardware" (Nickelson, 1992:5).

Soon after setting up ESCES, the Ministry of Communications decided to establish an international communication complex with an earth station, at Arvi near Pune. The government had nearly decided to employ a foreign company to set up the station on turnkey basis. However, Vikram Sarabhai, who headed the DAE and ISRO decided to build it locally. He felt that India was capable of developing all the systems required except the RF system, as most of them were mechanical systems such as antenna that would not pose serious manufacturing problems. To execute the project, ISRO also used other national organisations. Tata Institute of Fundamental Research (TIFR) was involved in the design and fabrication of the 29.5 m diameter parabolic reflector antenna, which was fabricated indigenously for the first time employing "about 300 tonnes of precision machined items" (Shah, 1992:10). The servo control and drive system was designed by the Babha Atomic Research Centre (BARC). In the field of multiplex and terminal facilities the "indigenous capability has been tapped to a very large extent" (DAE, 1970-71:149).

Most of the equipment was supplied by local industry.[1] Private firms such as the KCP, New Standard Engineering, Walchand Nagar Industries and a number of small-scale firms were involved (Shah, 1992:10). It was the first time that the industry was significantly involved in building ground systems. Overall, about 60 per cent of the systems were indigenously developed. However, the microwave systems were imported and an INTELSAT expert conducted the final tests (Rao, 1992:7).

It appears that construction of Arvi station using local resources had helped to create the necessary technical expertise to build similar earth stations at Dehra Dun, Bombay and Srinagar with limited foreign imports (DAE, 1969-70:72-73). The experience gained from the RF system imported for Arvi station helped ISRO subsequently to design and development indigenously all the RF systems required for earth stations to conduct the SITE. Only low noise parametric amplifiers were imported (Pant, 1992:8).

4.2. Ground stations for SITE and STEP experiments

When the SITE project was planned, the aim was to provide practical experience in the hardware and software aspects of satellite television broadcasting before establishing the operational Indian National Satellite (INSAT) system. The experiment used the NASA satellite ATS-6 from August 1975 to July 1976. ESCES (Ahmedabad station) was used as the prime station for the experiment that covered 2400 villages in six Indian states. SITE was "a total communication systems experiment involving both hardware (consisting of studios, satellite earth stations, ground receivers and various links) and software (consisting of formative research, programme production, evaluation and feedback)" (United Nations, 1981:10).

Apart from modifying ESCES with the assistance of the UNDP, ISRO had set up a backup station at New Delhi, and a receive-only earth station at Amritsar. As part of the ESCES expansion programme, a TV transmitter was also set up at Nadiad near Ahmedabad. ISRO had to set up a monopulse station at Nagpur for the attitude control of ATS-6 satellite. The 'transmit' and 'receive' chains, and S-band beacon transmitters for the Nagpur monopulse station were developed by ESCES. SAC and a private firm had supplied all the antennae required for Nadiad and other limited rebroadcast stations (DOSa, 1974-75:28-29).

The Ahmedabad earth station (AES) was the primary earth station for SITE. To provide support to the spacecraft from the station, NASA supplied the range and range rate equipment. For the Delhi earth station (DES), initially, it was planned to import the necessary equipment from NEC of Japan. However, due to delivery schedule problems, ISRO decided to develop them indigenously. The design, development, fabrication, and installation of the 9-m antenna and other equipment were completed in a short period of eighteen months (DOSa, 1975-76:30). The equipment for the earth stations at Amritsar, Nagpur, Madras were designed, developed and fabricated at SAC, Ahmedabad. The Post and Telegraph Department also supplied some equipment for the Madras station (DOSb, 1977-78:59 and 63).

As the experiment covered many un-electrified villages, ISRO needed to develop solid state TV receivers that could be operated from batteries. The ITU had recruited consultants from the British Aircraft Corporation to help the Indian design team (Nickelson, 1992:5). The experiment also needed converters, as the broadcasts could be received only through them. However, the technology was new at the time, as nowhere else was satellite TV being received at small terminals. Therefore, "to gain experience…two engineers were sent to work with the NASA team" at the Goddard Flight Centre, the US (DOSa, 1971-72:180). The engineers returned from the US and helped to develop the converters. Nonetheless, the project faced many problems and ISRO was forced to co-ordinate with other national agencies to successfully develop the converters.[2]

To produce television programmes for SITE, two studios were established in Bombay and Ahmedabad. The Ahmedabad studio was set up with aid from UNDP. It was a low-cost and easy to copy design allowing similar studios to be set up elsewhere in the country. A Canadian expert was brought in by the ITU to help to design the studio. The design provided "an affordable TV studio for a developing country, and was subsequently widely copied" (Nickelson, 1992:5).

After completing SITE, India conducted the Satellite Telecommunication Experiments Project (STEP) from June 1977 to June 1979 using the French-German satellite *Symphonie*. The aim was to provide "a system test of geo-synchronous satellites for domestic telecommunications and enhancing Indian capabilities" in ground systems technology related to satellite communications (DOSb, 1979-80:85). "Similar to SITE ground system, the entire STEP ground system is also an outcome of indigenous effort" (DOSb, 1977-78:59; 1978-79:62). It appears that the experience gained from SITE helped ISRO and the local industry to develop most of the ground equipment required for conducting STEP.

4.3. Development of Earth stations for remote sensing

Remote sensing activities began in 1969. Subsequently, rocket flights, balloons, and aircraft were used to carry out such surveys and the National Remote Sensing Agency (NRSA) was established at Hyderabad to co-ordinate these activities. Initially, India bought remote sensing data from the US and France. They were used to generate visual images and digital data for the users. To derive these data NRSA had set up facilities such as analysis facilities for digital data, and photo-lab and associated facilities for visual interpretation. These facilities were set up with a mix of internal resources and external funding. Some were set up under UNDP schemes and others with funding from Department of Science and Technology (DST). When NASA started making available the data from its satellites for direct reception to those countries that could set up earth stations, India decided to utilise this opportunity. In 1979, it set up an earth station at Shadnagar, Hyderabad, to receive remote sensing data directly from NASA's LANDSAT-2 and 3 and weather data from National Oceanic and Atmospheric Administration's (NOAA) satellites.[3] The earth station was bought from Scientific Atlanta, the US. A team of Indian engineers went to the US for training. Initially, it was planned to set up the station by an American team. Ultimately, the station was erected entirely by a team of Indian engineers that included those who were trained in the US.[4]

By the early 1980s, ISRO made an arrangement with NASA to receive data from its LANDSAT-4. For this, it decided to build a separate station indigenously. As ISRO and some local firms such as Prabhakar Products in Madras already possessed some expertise in building antennae, they were given the task of developing the antenna. The NRSA developed the control system. The feed system, the heart of the station, was imported, as India did not have local capability. Certain machine specific equipment like the data specific thematic mapper, data extractor and data conditioner were also imported. As LANDSAT-4 failed, this station was used to receive data from LANDSAT-5. In 1986, the station was augmented to receive data from the French satellite SPOT. The augmentation component was also built locally. Again, when India planned to launch and operate its national remote sensing system, the IRS-1 satellites, it needed a station wholly devoted to IRS-1s, but also capable of receiving data from other satellites. Coincidentally, as LANDSAT-2 and 3 went out of service, the earth station that was bought from the US in 1979 for them became free and it was modified to receive data from IRS-1s. This modification mainly involved upgrading of receiving section. SAC was able to develop the complete feed and receiving sections. All the sub-systems for the IRS data reception facility such as the composite feed, low noise amplifier, down converter and demodulator were developed indigenously between 1984 and 1987 (DOSb, 1986-87:32). Figure 4 illuminates the process of competence building in remote sensing earth station systems. It appears that by late 1980s, India has acquired threshold capabilities to design and develop the remote sensing earth stations. However, it continued to depend on imports for some important parts, such as radar components, which were not manufactured in India.[5]

5. Exports

Since mid-1990s, India started exporting and providing consultancy and training in the area of ground systems through the Antrix Corporation Limited, the commercial arm of DOS/ISRO. During 1994-95, Antrix won contracts for the definition of space design, implementation and evaluation of small omnidirectional L/S/UHF Antenna for INMARSAT-P hand held phone and it supplied different versions of this antenna to INMARSAT. Antrix also carried out the bench marking of FORTRAN programmes for IBM and for agencies in Singapore. India provided training for South Korean engineers in mission control and satellite system definition (DOSb, 1994-95:62). Following an agreement with Earth Observation Satellite Company (EOSAT) of the US for marketing IRS data world-wide in 1994, India supplied the equipment and software for establishing IRS reception capability to a number of earth stations in different counties. This included Norman in the US, Neustralitz in Germany, ground station of National Research Council of Thailand (NRCT) in Bangkok, stations in Japan, Dubai, South Korea, Australia and Saudi Arabia. In 1996, Antrix supplied packet telecommanding software subsystem to Telespazio of Italy. During 1998-99, India has established and started operating a Telemetry Control & Ranging (TCR) station for supporting a digital audio broadcasting satellite system that was set up by World Space Inc. An agreement was reached with Electronic and Telecommunications Research Institute (ETRI) of Republic of Korea to provide engineering and technical consultancy for setting up a spacecraft control centre. Since mid 1990s, India also started providing Telemetry, Tracking and Command (TTC) support to foreign satellites on commercial basis. (DOSb, 1995-96:70; 1998-99:85-86).

6. Role of foreign and indigenously inputs

The competence building process between the 1960s and 1990s in India's space programme suggests that India was able to effectively combined foreign imports with indigenous effort from the beginning. Figure-1 illustrates the space technology accumulation process in India during this period. Tables 1 to 3 show the balance between foreign and indigenous technological inputs during different periods.

Although ground systems technology was relatively less complex compared to rocket and satellite technologies, it appears that India considered foreign collaboration was necessary to learn various skills such as designing, fabricating, testing, and installing of systems. At the same time leading space scientists were aware that they had to make strong and sustained indigenous efforts by employing available resources. When India set up its first launching station, TERLS, in the early 1960s, India's capability in building ground systems was very limited. Although Indian industry was capable of meeting certain demands, it was inexperienced and its manufacturing capacity was mainly restricted to mechanical engineering. Particularly in electronic systems, India appears to have been completely dependent on foreign imports. By mid 1980s, India was able to build threshold capabilities in most areas of ground systems technology. By late 1990s, India appears to have acquired high level of capabilities in nearly all ground systems, which is reflected by its exports of equipment and software, albeit in small scale. It also started providing training and consultancy to other countries in design, fabrication and evaluation of ground systems equipment. India also started establishing and operating spacecraft control stations on commercial basis for supporting foreign satellite sytems in small-scale.

It is clear that foreign collaboration played an important role particularly during the *formative phase* of competence building, that is, until the mid-1980s (see Tables 1 and 2). In the area of rocket launching and spacecraft control systems, ISRO's close relationship with other national space agencies and its involvement in international scientific projects had enabled it to receive considerable technical assistance from the US, the former Soviet Union, the UK, France and Germany. In the area of earth stations for satellite communications and remote sensing, India received considerable assistance in the form of funding, training and technical consultancy from international bodies such as UNDP and ITU. Foreign space agencies such as NASA, CNES, and DFVLR also helped India by providng satellites for experiements such as SITE and STEP, training, testing of components and subsystems made in India, and in some cases equipment for earth stations. However, during this phase, it was also clearly evident that India was making strong efforts to develop locally whatever components and subsystems it could by using existing knowledge and capabilities.

By the mid-1980s, India appears to have achieved threshold capabilities in ground systems technology. Since then, that is, during the *accumulative phase*, it is evident that foreign technological inputs have significantly declined and the indigenous efforts started playing the main role in competence building (see Table-3). This trend is clear from various development projects such as building and modifying new earth stations, spacecraft control and tracking stations, and continuous augmentation of exisitng rocket launching stations. During this phase, India appears to have accumulated a high level of capabilities in all areas of ground systems technology. However, it also continues to import critical subsystems and components in the area of microelectronics and materials. Although India is still dependent on imports, as as ground systems are becoming more complex, it is likely that the role of foreign technological inputs in competence building in future will decline further.

The following factors seem to have helped India to gradually reduce foreign technical assistance and imports: (i) the relatively less complex nature of technology; (ii) the experience accumulated by ISRO over the years; (iii) increasing manufacturing capacity of the industry; and (iv) creation of linkages among ISRO, other R&D institutions, universities and industry. From the beginning, ISRO actively fostered local firms as it believed that industry was more capable of executing projects in this area than in satellite and rocket projects. With a steady increase in the number of new projects such as SITE, STEP and Earth stations for LANDSATs, the demand for various systems and equipment also increased. Simultaneously, India was experiencing foreign exchange difficulties that put restrictions on imports. Therefore, ISRO started developing local firms to meet as much demands as possible. For example, initially the remote sensing data processing systems were imported mainly from the US and Canada. Over the years, with the establishment of IRS system, both the number of user agancies and the demand for data processing systems have increased mnany fold. The increase in demand coupled with foreign exchange difficulties forced ISRO and NRSA to develop these systems indigenously so that they could be obtained cheaply within the country. As a result many new firms emerged, especially, in Hyderabad and Bangalore, to meet this demand. Now, it seems that nearly all the hardware and software for data processing systems are locally available.

ISRO actively fostered supplier firms by providing technological know-how, training, quality management skills and by sharing information and facilities. The firms were involved in proto-type development, engineering, research and development (R&D) related to fabrication problems and final production. ISRO also encouraged major suppliers to use sub-contractors to cut down cost and development time. This appears to have created a network of sub-contractors that led to wider technology diffusion in the industry. The quality management system developed by ISRO has been passed on to sub-contractors level. ISRO also used other R&D organisation and academic institutions such as BARC, Indian Institute of Technology (IITs) and universities to execute its projects. Over the years, it fostered linkages among firms and various institutions that helped to develop an efficient innovation system. India’s exports in the 1990s suggest that it was able to enter the international market in the areas of satellites and ground systems in a small way. It is likely that India may play a major role as exporter in future, as satellite technology and their usage spread to more developing countries. The cheap availability of skilled labour and capability to produce high quality equipment and subsystems are likely to help India to export both expertise and goods. However, it is also likely that India will continue to depend on foreign imports to keep pace with rapid technological changes. This suggests that competence building in high technology such as space systems in a developing country would continue to depend on considerable foreign inputs, even after it reached threshold level.

7. Conclusions

This paper has shown that India has built a high level capabilities in ground systems technology by effectively combining foreign and indigenous technological inputs. Collaboration with other countries and international organisations helped India's effort to build capabilities in this area, particularly during the *formative phase* (from the late-1960s to mid-1980s). When India dedicated TERLS as a UN sponsored launch site for the use of international community, it has helped India to work closer with other countries like the US, the former Soviet Union, West Germany and France. During this phase foreign imports played an important role in competence building process. India was dependent on imports for nearly all critical sub-systems and components. In contrast, during the *accumulative phase* (from the mid-1980s), the imports were restricted to a small number of items, which could not be fabricated locally. It is also clear that although India started exporting hardware and expertise, it continues to depend on foreign technology, to keep pace with technological change. This demonstrated that foreign technological inputs in some form are necessary for technology accumulation in developing countries even after it attains threshold capability. Although foreign imports are less important in the *accumulative phase* than in the *formative phase*, they appear to play a significant role in all phases.

The evidence also showed that India made strong indigenous efforts from the beginning. It was evident from the implementation of various technology development projects in the 1960s and 1970s. For example, the internal effort played a major in Rohini sounding rocket project (in the 1960s), in SLV-3, Aryabhata, Bhaskara I and II, SITE and STEP projects (in the 1970s). These developments suggest that without strong indigenous effort India would not have achieved threshold capability by mid-1980s. It is evident that both internal and external knowledge played major roles in the process of technology accumulation, although their degree of contribution differed in different phases. The nature of combination of internal and external knowledge appears to have determined the rate of technological accumulation at a given time.

India's experience in the ground systems technology also demonstrated that competence building in developing countries even in relatively less complex systems is a long-term process that required substantial foreign technological inputs and sustained indigenous effort. This is clearly demonstrated by the time taken by India to achieve threshold capability and to enter export market. India took about 20 years to attain threshold capabilities and it took another 10 years to make a small headway in export market. This suggests that competence building in developing countries in general is a a long-term process, which demands sustained investment in terms of financial and human resources over a number of years.

To generalise, it is clear that both external and internal knowledge appear to play important roles in competence building in developing countries. Although their role may differ in different period of competence building process, both appear to play a complementary role. They appear to determine the rate and shape of technology accumulation, when they are combined. Further, competence building even in slightly complex technology such as ground systems in developing countries requires high level of R&D, industrial capacity, project management and co-ordination skills, and forging of linkages among various institutions. Therefore, it is likely that a large number of developing countries including some advanced countries would find it difficult to build capabilities in such technologies, leave alone the more complex ones, as many of them do not have these resources. Competence building in general also involves long lead-time (about 25 to 30 years) and significant long-term investment. This demands political will and a major role for the state. It is unlikely that developing countries would be able to build technological capabilities without state intervention.

Figure 1: Ground Systems Developed in India's Space Programme

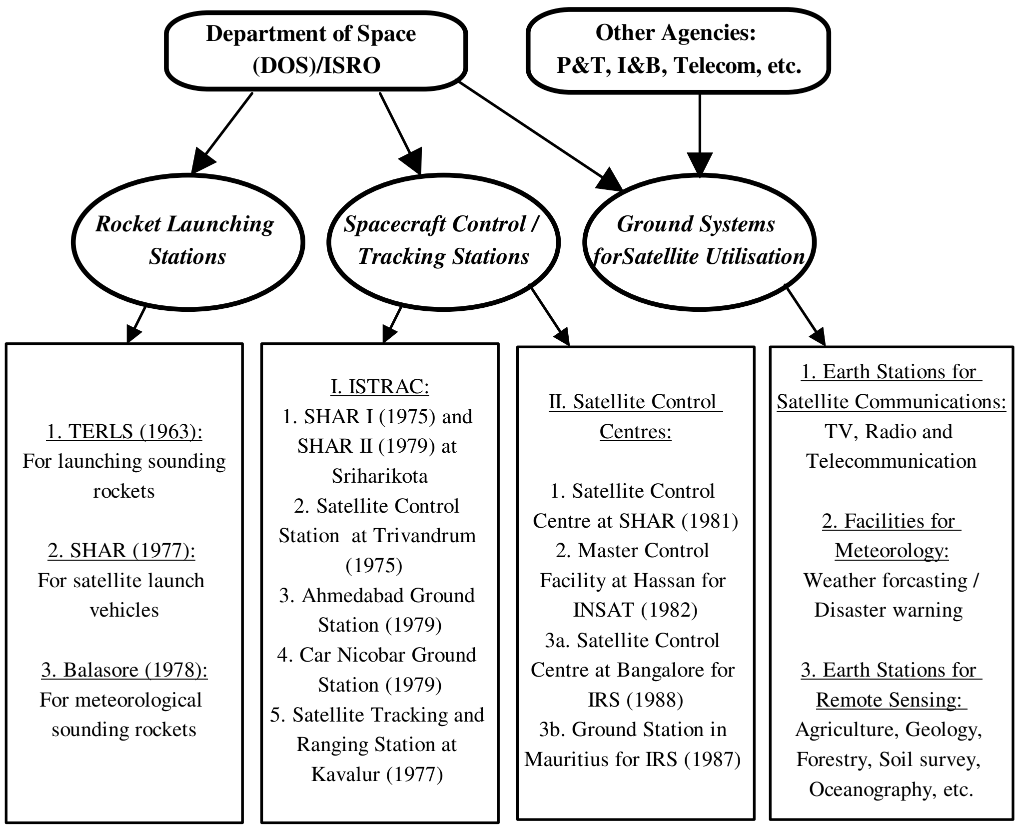


Figure 2: Foreign and Indigenous Inputs in Developing Rocket Launching and Satellite Tracking/Control Systems

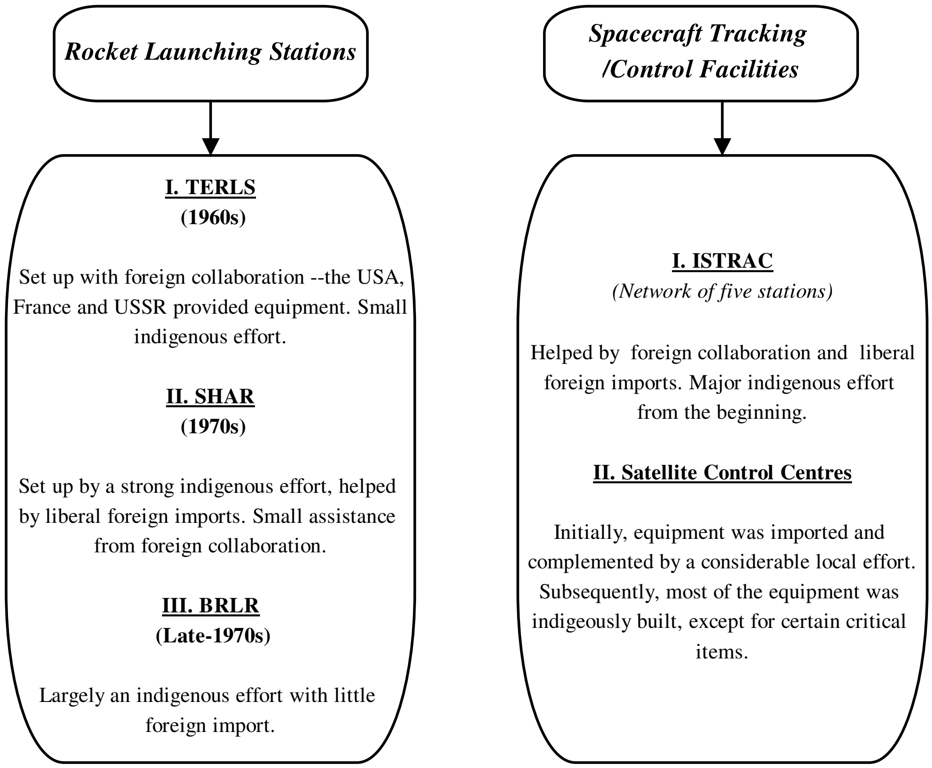


Figure 3: Foreign and Indigenous Inputs in Building in Earth Station Systems for Satellite Communications

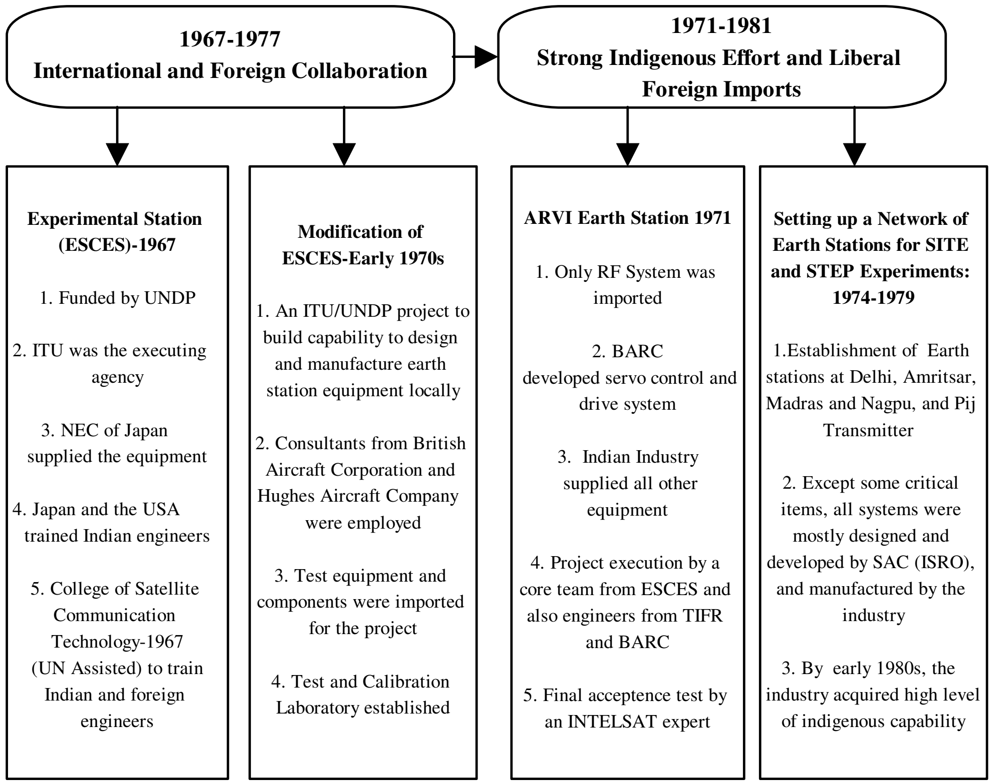
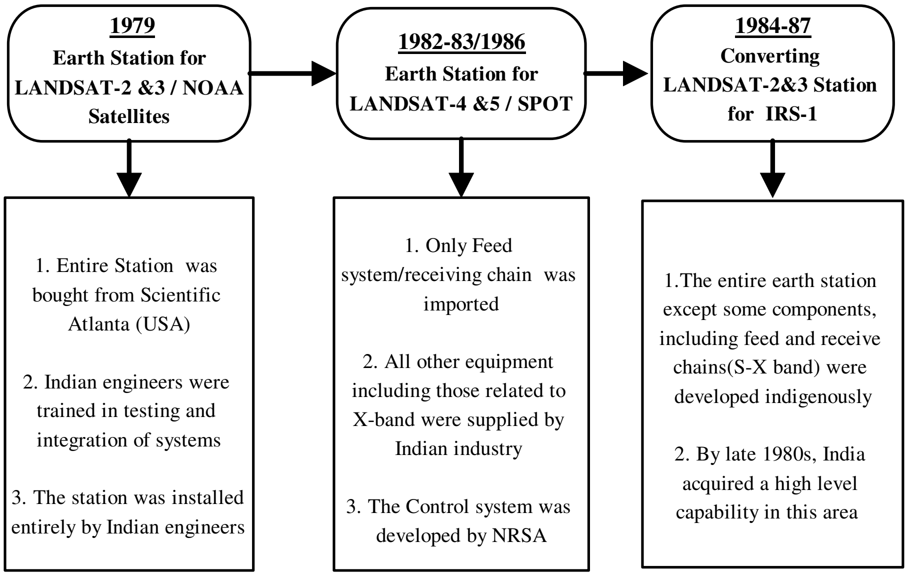


Figure 4: Foreign and Indigenous Inputs in Developing Earth Station Systems for Remote Sensing



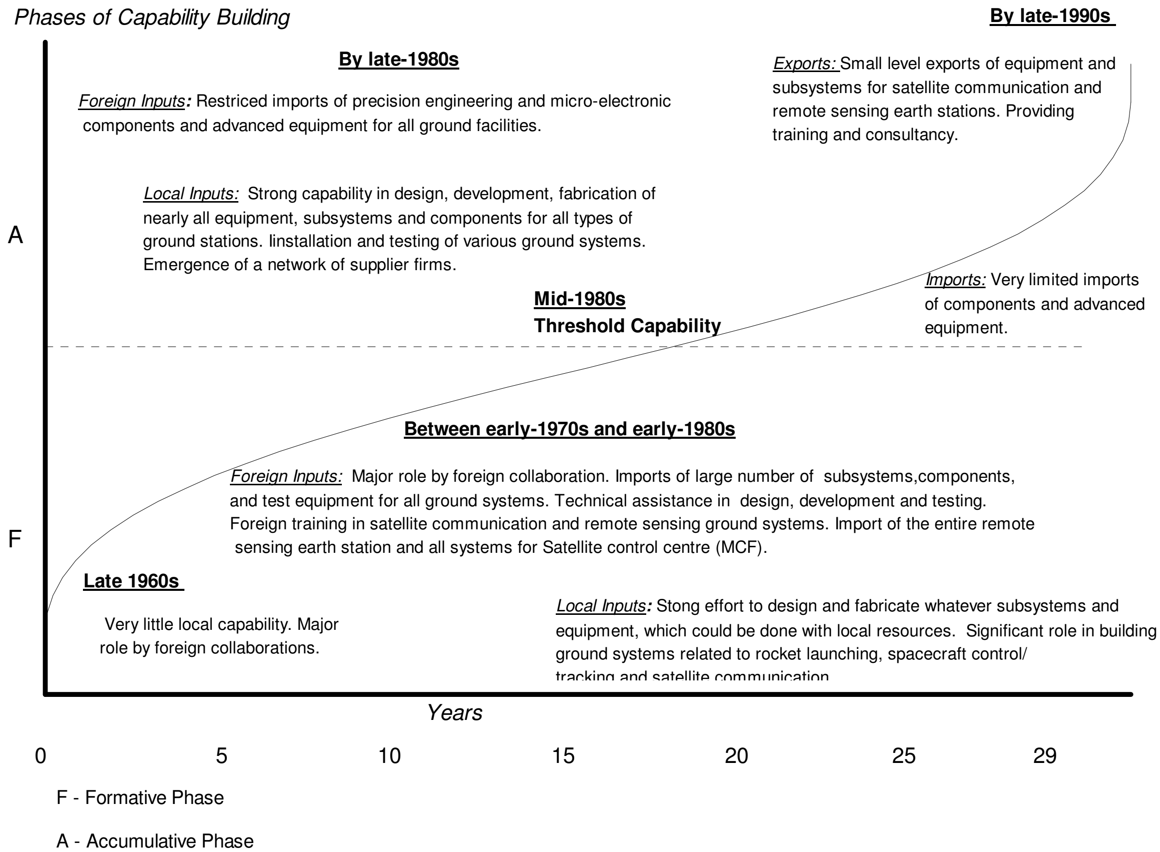


Figure 5: Process of technology accumulation in ground systems in India's space programme (late 1960s to late-1990s)

Table 1: Balance between foreign and indigenous inputs in the technology accumulation process from the mid-1960s to early-1970s

Period and Projects	***Foreign Inputs***	***Indigenous Inputs***
1. Thumba Rocket Launching Station (TERLS)	(a) Established with foreign collaboration. (b) Equipment such as Cotal radar (CNES - France), Tone ranging system (NASA - the US), and Minsk-II computer, Radar tracking station (Soviet Union) were donated.	(a) Initially, less complex items were made locally. Subsequently, an R&D unit was set up to develop ground systems. (b) Universal launcher for Nike- Apache and Centaure rockets, launchers for British Skua and Russian M-100 rockets, test and evaluation facility, VHF telemetry receiving station, and S-band radar. Designing small satellites.
2. Experimental Satellite Communication Earth Station (ESCES) / Ahmedabad Earth Station (AES)	(a) Set up with United Nations Special Fund. (b) International Telecommunication Union (ITU) provided technical expertise and executed the project. (c) Nippon Electric company (NEC), Japan, supplied the equipment. (d) Japan and US trained Indian engineers. (e) College of Satellite Communications Technology was set up with UN funding and UN experts assisted in running training courses.	(a) Very little local input. (b) Indian engineers were involved in executing the project.
3. Arvi Earth Station *(Overseas Communication Service/INTELSAT)*	(a) The microwave systems were imported. (b) INTELSAT expert carried out final tests. (c) About 40 per cent imported content.	(a) The 29.56m diameter antenna system. (b) Servo control and drive system. (c) Other mechanical subsystems and equipment. (d) Project execution by team of engineers from ESCES and other R&D institutions such as TIFR and BARC. For the first time, major involvement of the industry. (e) About 60 per cent indigenous content.

Table 2: Balance between foreign and indigenous inputs in the technology accumulation process from the early-1970s to early-1980s

Period and Projects	***Foreign Inputs***	***Indigenous Inputs***
1. Sriharikota Range (SHAR) and Balasore Rocket Launching Range	(a) Little foreign collaboration. (b) Imported a number of subsystems, components, instruments and testing equipment to set up various facilities such as SPROB and STEX. (c) Imported PCM telemetry equipment and nearly all computers for data processing. (d) CNES donated Cotal radar. All critical sub-systems for different types of radar were imported.	(a) Launching pad for 300mm and 560mm diameter rockets, telemetry and tone ranging systems and subsystems for FM/FM telemetry stations were developed at TERLS. (b) Acquisition and tracking radars, a C-band radar, telecommand system for rocket launch and satellite operation, and tone range and telemetry interferometer system were developed at VSSC in collaboration with SAC, BARC, TIFR and others.
2. Satellite control and Tracking stations - *ISRO Telemetry, Tracking and Command Network (ISTRAC)*	(a) A number of critical subsystems and components were imported. (b) Soviet Union and East European countries provided equipment and helped to set up an optical satellite tracking and ranging station.	(a) ISRO centres developed various subsystems. (b) ISRO supplied necessary supplementary equipment to Kavalur station and set up observatory and laboratory facilities.
4. Master Control Facility (MCF) for INSAT-1s	(a) Ford Aerospace established the Satellite Control Centre. (b) Imported several critical items.	(a) Most equipment for earth stations. (b) Electronic systems, 14-metre diameter fully steerable antenna systems and no-break power system.
5. Earth stations for Satellite Communications *(ESCES modification and Earth stations set up for SITE and STEP experiments at New Delhi, Amritsar, Madras, Nadiad, Nagpur, and remote and emergency terminals (TRACT and ECT)*	(a) Financial and technical assistance from UNDP/ITU to modify ESCES, to design and develop a TV studio for SITE and technical consultancy from foreign companies. (b) Foreign equipment and components for test and calibration laboratory. (c) NASA's range and range rate equipment for AES. Limited imports for other earth stations. (d) NASA training to develop front-end converters for SITE. (e) Expertise from British Aircraft Corporation helped to develop Solid state TV receivers.	(a) Major indigenous effort for ESCES modification project. The uplink chains were locally designed and developed. (b) Design, fabrication and installation of antenna and other equipment required for all other stations. (c) SAC developed and supplied high power amplifiers, transmit and receive chains for earth stations to conduct STEP. P&T Department also supplied equipment. VSSC provided testing and analysis of equipment. (d) The industry supplied a number of items such as antenna reflectors and mounts for earth stations.
6. Earth stations for Remote sensing	(a) The first earth station for LANDSAT-2 and 3 was entirely bought from the US. Also, Indian engineers were trained in the US. (b) Only feed/receiving chain was imported for LANSAT-4/5 station.	(a) The first station was installed entirely by Indian engineers. (b) For LANSAT-4 and 5 earth station, the control system was developed by NRSA and other equipment was supplied by the industry.

Table 3: Balance between foreign and indigenous inputs in the technology accumulation process from the mid-1980s to late-1990s

Period and Projects	***Foreign Inputs***	***Indigenous Inputs***
1. Augmentation of Sriharikota Range (SHAR)	(a) Imports limited to some critical subsystems and components. (b) Collaboration with German space agency DFVLR to design and develop ISRO computer networking system.	(a) VSSC developed PCM telemetry. (b) Long range precision tracking radar and PCMC radar for PSLV were developed by BEL. (c) Locally developed computer systems for data acquisition and processing. (d) Nearly total capability in design and development of telecommand systems. (e) By late 1980s, strong indigenous capabilities in all areas.
2. Spacecraft control and tracking (ISTRAC)/ Master Control Facility (MCF) for INSAT-2s	(a) Very little imports. (b) Only some micro-electronic components and materials that could not be made locally were imported.	(a) Major indigenous effort to augment and improve the existing stations, e.g. from VHF and C-band to S-band capabilities. (b) To augment MCF for INSAT-2s, the antenna, all C-band equipment and tracking receiver were supplied by the industry. (c) By the late 1980s, ISRO centres and the industry started meeting nearly all the demands.
3. Earth stations for Satellite Communications	(a) Only some critical items were imported to augment these stations for the next generation satellites. (b) By the late 1980s, very little imports.	(a) The equipment and subsystems required to augment the stations were mostly designed and developed by ISRO centres and manufactured by the industry. (b) By the late 1980s, industry acquired a high level of capability.
4. Earth stations for Remote sensing	(a) For IRS earth station, only some critical components were imported. (b) By the late 1980s, very little imports.	(a) For IRS earth station, nearly all equipment and subsystems except some components including feed and receive chains were supplied locally. (b) By late 1980s, very extensive indigenous capability.

Notes

[1]Interview with Dr. Pramod Kale, Former Director of SAC.

[2]Interview with Prof. Yashpal, Former Director of SAC, ISRO, Ahmedabad.

[3]The earth station is comprised of the antenna, control system, the feed and RF system (the receiving part), and the equipment to record the data. The last two involve many critical items and some of them are Laser components.

[4]Interview with R. Kasturi Rangan who was one of the members of the team and former Operations Manager, IRS-1A Data Collection Platform, NRSA, Hyderabad.

[5]Interview with Dr. D. V. Raju, Former Deputy Director of NRSA, Hyderabad.

References

Bell, M., and Scott-Kemmis, D. Report on a Study of Technology Transfer and the Accumulation of Technological Capacity in Manufacturing Industry in Thailand. Science Policy Research Unit, University of Sussex, Brighton, 1985.

Bell, M., and Pavitt, K. Technological accumulation and industrial growth: Contrasts between developed and developing countries. Industrial and Corporate Change 1993; 2(2):157-210.

Department of Atomic Energy (DAE), Government of India, Bombay. Annual Report, 1961-62 to 1971-72.

Department of Space (DOSa), Government of India, Bangalore. Annual Report, 1972-73 to 1998-99.

Department of Space (DOSb), Government of India, Bangalore. Performance Budget, 1975-76 to 1999-2000.

Enos, J. L. The creation of technological capability in developing countries. London: Pinter publishers, 1991.

Enos, J. L., and Park, W. H. The adoption and diffusion of imported technology: The case of Korea. London: Croom Helm, 1988.

Hobday, M. The innovation in East Asia: The challenge to Japan. Aldershot, UK: Edward Elgar, 1995.

Katz, J. M., ed. Technology generation in Latin American manufacturing industries. London: Macmillan press, 1987.

Kim, L., and Lee, H. Patterns of technological change in a rapidly developing country: A synthesis. Technovation 1987; 6(4): 261-276.

Kim, L. National system of industrial innovation: Dynamics of capability building in Korea. In: Nelson, R. R., editor. National innovation system: A comparative analysis. New York: Oxford university press, 1993.

Kim, L. From imitation to innovation: Dynamics of Korea's technological learning. First draft, Brighton: Science Policy Research Unit, 1996.

Lall, S. Learning to industrialise: The acquisition of technological capability by India. London: Macmillan press, 1987.

Lall, S. Building industrial competencies in developing countries. Paris: OECD, 1990.

Nickelson, R. Maximising indigenisation in ESCES. SAC Courier (SAC/ISRO) 1992; 17(1): 5.

Okerjiri, E. Foreign technology and development of indigenous technological capabilities in Nigerian manufacturing industry. Technology in Society 2000; 22(2): 221-235.

Pant, N. Implementation of ESCES. SAC Courier 1992; 17(1): 8-9.

Patriot. New Delhi, Various years.

Rao, K. R. On initiation of ESCES, and its benefits. SAC Courier 1992; 17(1): 6-7.

Shah, M. M. Antennae: ESCES and ARVI and Beyond. SAC Courier 1992:17(1): 10.

Times of India. New Delhi, Various years.

United Nations. Second United Nations conference on the exploration and peaceful uses of outer space. National paper: India, A/CONF.101/NP/6, 1981.

Westphal, L. E., Kim, L., and Dahlman, C. J. Reflections on the Republic of Korea's acquisition of technological capability. In: Rosenberg, N., and Frischtak, C., editors. International technology transfer. New York: Praeger, 1985.

Zhao, H. Technology imports and their impacts on enhancement of China's indigenous technological capability. Journal of Development Studies 1995; 31(4):456-60