Organizational systems, commercialization and cost–benefit analysis of Indian space programme

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During the last four decades, ISRO has developed capabilities and infra-technologies in broadcasting, communications, meteorology, remote sensing and space science research and has made significant contributions to several areas of national development. The organizational systems of ISRO have been designed to ensure maximum autonomy, creative and innovative environment that are conducive for a performance-oriented system, besides developing unique institutional mechanisms for participation of industry, academia and user agencies. Project/mission mode of working has been a hallmark of ISRO. The satellites and launch vehicles of ISRO have been cost effective and the benefits derived from the space programme have exceeded the costs. Commercialization of India's space capabilities received impetus through Antrix Corporation, which has set a new model by adopting a very lean and efficient structure for marketing of space products and services. This article discusses the unique organizational feature of ISRO, the salient aspects of commercialization and cost–benefit aspects of India's space programme.

Keywords: Commercialization, cost–benefit analysis, organizational systems, project management, space programme.

INDIA has developed world-class satellites and launch vehicles and mastered the technology of utilizing the space systems in several areas relevant to national development. The focus of the Indian space programme has been on (a) application of space technology as a tool for socio-economic development of the country, and (b) to achieve 'self-reliance' in this strategic area. In consonance with this objective, India has established two operational space systems, viz. INSAT system, which is one of the largest domestic satellite communication systems in the world and the Indian Remote Sensing Satellite (IRS) system, which has among the best satellites in the world for generating information on natural resources. India's Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV) provide self-reliance in launching IRS and INSAT satellites. India has also undertaken significant research in space science and planetary exploration through missions such as Chandrayaan. The recent launch of Italian 'Agile' satellite by India's PSLV on 23 April 2007 is a major landmark in commercialization of India's launch capability.

The remarkable achievements of India in the field of space have been well acknowledged world-wide. The conception, design, development and successful realization of complex elements of space technology tailored to India's developmental needs required efficient organizational systems and innovative institutional structures[1]. As investments in space programme grew, it was necessary to justify the budgetary requirements in terms of economic returns and social benefits. This article deals with organizational systems, cost–benefit analysis and commercialization aspects of Indian space programme.

Organizational systems

The organization structure of ISRO/DOS has evolved over the years (Figure 1). The structure is based on a network of ISRO centres and units, industry and academia. They

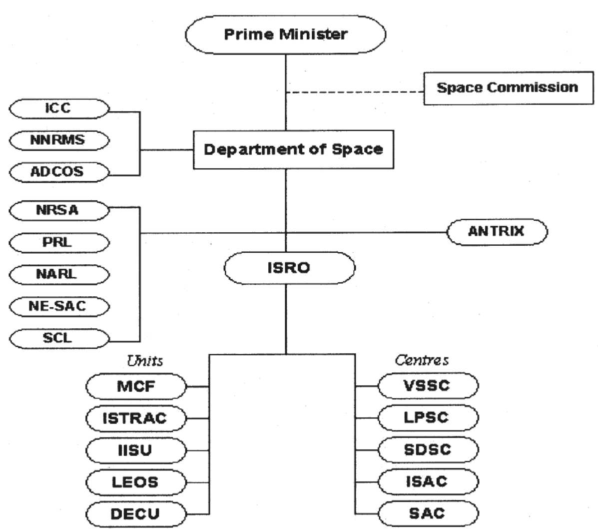

Figure 1. Organization structure of ISRO/DOS.

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provide the resource base required for realizing the projects and missions. ISRO centres and units have been created in a phased manner over the years as Centres of Excellence in various fields of space science, technology and applications. The activities of Vikram Sarabhai Space Centre in Thiruvananthapuram, from where the space programme started, have encompassed development of rocket systems, spacecraft technology, space science as well as space applications. As the activities grew, separate centres have been formed for liquid propulsion systems, inertial systems, satellite development, payload development, space applications and space operations. Today, ISRO has ten centres and units spread over Thiruvananthapuram, Sriharikota, Bangalore, Ahmedabad and Hyderabad from where the space programmes are being executed.

A key feature of ISRO/DOS organization is its 'Project and mission mode of working'. Based on demand for space services and the long-term plans, specific projects in the area of launch vehicles, satellites, ground systems and space applications are conceived, undertaken and executed in a time-bound manner. Once the objectives are achieved, the projects are closed and the resources are redeployed for other ongoing projects. The projects are being executed by the ISRO centres and units under matrix management structure to ensure optimum utilization of resources. Each project, being multi-institutional and multidisciplinary in nature, required unique systems engineering practices such as configuration control, data management and project review systems with focus on achieving the results within the time and cost limits. The project mode of working thus gave the much needed 'result-oriented approach' in the organization besides establishing unique project management practices.

An important outcome of the space programme is a unique project management structure to constantly review and monitor the progress and performance of the projects. A two-tier structure comprising a Project Management Council (PMC) and Project Management Board (PMB) (Project Executive Committee in some projects) provide the overall framework for the functioning of the project. PMC, chaired by the lead centre director, usually a distinguished scientist, provides the overall direction for the project covering technical, managerial, financial and resource allocation aspects. PMB, chaired by a Project Director, meets more often to discuss and resolve the issues concerning the project progress. These apart, a key strategy has been to carry out an in-depth and critical technical review of the project upon achieving specific progress milestones such as preliminary design, detailed design, proto fabrication, flight readiness, etc., wherein experts outside ISRO also participate. Thus the project management structure for constant review and evaluation of the activities during their implementation has been a key factor in achieving the programmatic targets in the space programme. Figure 2 shows the key elements of the project management strategy.

Space programme being predominantly application-driven, inter-linkages with other user departments are crucial for end-to-end capability. The experience gained in the experimental phase with Bhaskara satellite, APPLE satellite, SITE and STEP experiments paved the way for creation of exclusive mechanisms for user interface. INSAT Co-ordination Committee (ICC), Planning Committee-National Natural Resource Management System (PC-NNRMS) and Advisory Committee on Space Research (ADCOS) are the three principal institutional frameworks designed to provide effective user interface for the space systems. ICC comprising secretaries of the user departments of INSAT system (such as Department of Telecommunications, IMD, Prasara Bharathi, etc.) provides operational co-ordination, guidelines for planning of INSAT system, prioritization of transponder requirements and other technical issues related to utilization of INSAT. PC-NNRMS chaired by Member (Science), Planning Commission co-ordinates the implementation of space-based remote sensing for various applications. To ensure efficient and coordinated use of the remote sensing data at the centre, region, states, districts and villages, PC-NNRMS has formed a Standing Committee for various themes such as Agriculture and Soils, Geology and Mineral Resources, Water Resources, etc. ADCOS consisting of national level space scientists co-ordinates the space science research in the country. These special structures evolved for user interface have played a crucial role in sustaining various space endeavours and they have been unique features of Indian space programme[2].

An important feature of the planning process in ISRO has been the Decade Profile. Since inception, the space programme was always guided by Decade Profile which sets goals and directions in the organization for long lead technology development and investments. Through the Decade Profiles, the organization commits itself to the nation on the long-term programmatic targets and strives to achieve the targets through Five-Year Plans and Annual Plans. The participative approach adopted in the goal-setting process makes those responsible for achieving the goals committed to the targets set. Specifically, in initiatives of strategic nature such as indigenous development of a subsystem/part/material hitherto imported, development of a critical technology with a target to qualify and implement it in a project of immediate relevance, the process of setting time and performance targets and working in a mission mode to achieve the targets has yielded rich dividends. Thus the goal setting process is effectively used in the space programme to achieve higher performance.

Recognizing that outer space belongs to all humankind and is to be used for the welfare of all, international co-operation assumes significant importance in the overall framework of organizational systems. India has forged bilateral and multilateral relations with many space agencies in the areas of climate and environment, space science

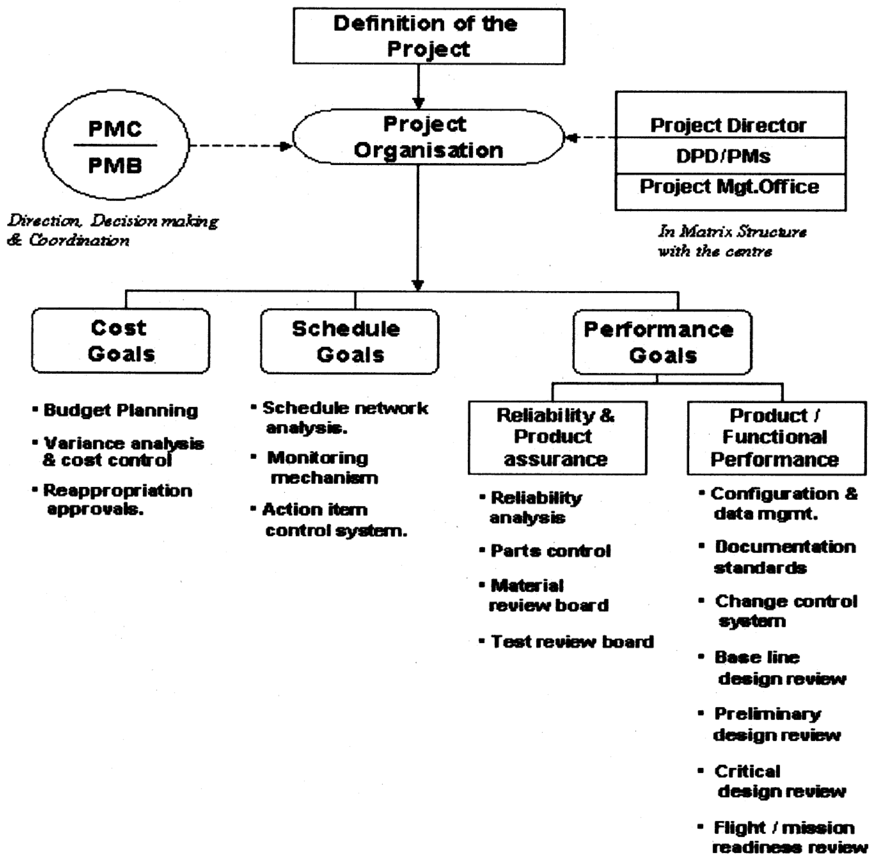

Figure 2. Key elements of Project Management Strategy.

and other areas of global concern. India has also registered a strong presence in international forums such as United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUS) dealing with space policies and co-ordination of space operations[3]. The rich dividends emanating from the strategy of international co-operation are evident from the overwhelming response received from international community for participation in India's first Lunar Mission Chandrayaan-1 through the payloads of opportunity.

Development of human resources has been a key strategy of ISRO from the very beginning of the space programme. ISRO has been very careful in spotting and recruiting the very best quality manpower to take up its challenging tasks. The organizational systems designed to ensure maximum autonomy for the scientific work, promote innovativeness and risk taking, communication channels that are free from organizational barriers and project mode of working have nurtured to develop an extraordinary level of commitment in the people, which has been a major strength of ISRO. The partnership launched with the academia through sponsored research programmes has been a significant step in capacity creation in universities/educational institutions to undertake research projects of relevance for space.

Commercialization

Space commerce – Global scenario

Globally viewing several products and services based on space technology have been successfully commercialized in all major space-faring countries as well as those which utilize the services derived from space. The most prominent among such items are communication satellites, which offer services for television/video, telephony, radio and data communications. Commercial activities were also developed around remote sensing satellites by commercializing the applications of data gathered by them, although these were initially developed as public good investments. Launch services for orbiting these satellites in different orbits were undertaken by industries in the USA, Europe and more recently in Asia. A vibrant industry in private sector is now a reality, particularly in the USA and Europe to provide diverse elements of space infrastructure and also services using space systems.

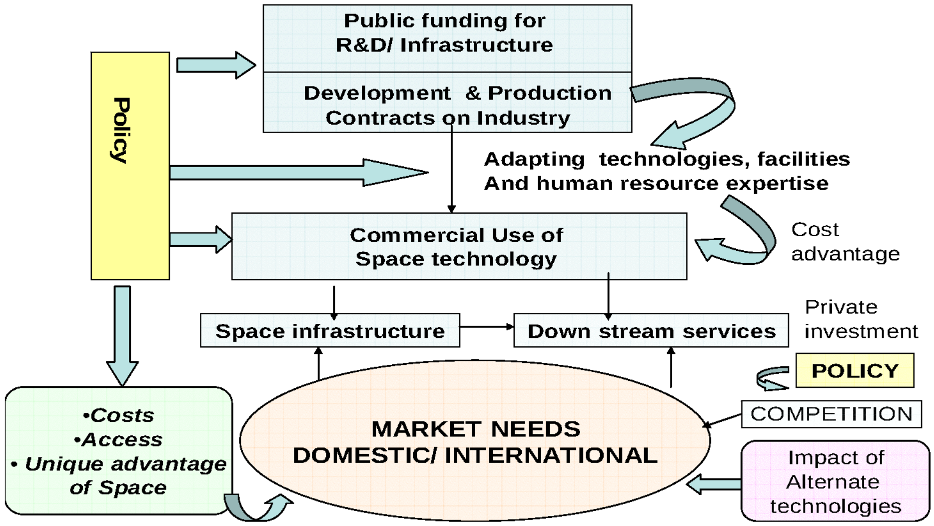

Figure 3. A model for space commerce.

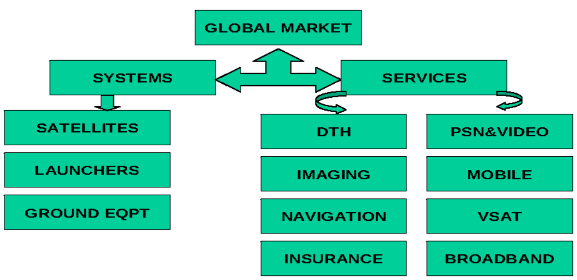

Figure 4. Structure of global space markets.

If one considers the capital intensive character, high risk and the long gestation of return on space project investments, the evolution of commercial industry, particularly in infrastructure segment, would have been a tall order but for a substantial public funding support for technology developments and the anchor tenant role of governments in purchase of products and services. The initial decades of space era, which was enveloped by the cold war atmosphere triggered large expenditures in space systems by rival powers for establishing military superiority or enhancing national prestige or strategic independence. This enabled private industries in countries such as the USA to undertake contracts for the government to develop and produce systems, that were spun off for commercial uses. A model, which thus emerged as a foundation for commercial space activities, is illustrated in Figure 3. It is also noteworthy that integration between space and aircraft industries has also brought about optimization of resource use. The further evolution of commercial space in the post cold war period is still heavily influenced by government policies witnessing a drive towards privatization of intergovernmental systems which provide services from space and opening of markets for services by the private sector. The commercial space activities in the present era are mainly shaped by three diverse forces of geopolitical considerations including security needs, socio-economic relevance and technology advances.

Commercial space industry environment today is influenced by strong intervention of governments with regard to policies on technology transfers, market access and risk sharing besides international legal environment for activities in outer space. These factors often translate into considerable entry barriers to late entrants to the game and also in defining competitive landscape and in limiting collaborative environment.

The present structure of global commercial space market is illustrated in Figure 4.

The overall revenue from commercial space activities in 2005 was estimated to be US$ 110 billions, of which US$ 80 billion has been taken by satellite services industry. The status of space industry in commercial sector as recorded in a report by the Space Foundation of USA[4] published in 2006 is illustrated in Table 1.

Evolution and growth of commercial space activities in India

The evolution towards commercial activities in space in India has taken a slightly different path as compared to the model followed in the western part of the globe. Indian space effort, implemented by ISRO evolved as a purely civilian programme, with the objective of using modern space technology towards accelerating the nation's socio-economic development.

During the early stages of space programme in India, the industrial back-up and private sector investment for space activities were minimal and ISRO directly undertook establishment of necessary process expertise and facilities to undertake design, development, manufacturing, assembly and testing of the space systems. In the mid-1970s, ISRO initiated a technology transfer programme to empower Indian industry to undertake manufacture of various products and services for national space projects. Industry started providing ISRO centres with a variety of hardware and software including the propellants, structures for satellites and launch vehicle systems, electrical modules and subsystems, a variety of materials, components, ground systems and test equipment[5]. The technology transfer programme was highly successful in farming out a substantial portion of manufacturing activities to industry and the industry derived several spin-offs including their involvement in markets related to space applications and imbibing the culture and practices associated with high degree of reliability and quality assurance. Impact of this policy was that about 35% of ISRO's budgets are spent in industry for contribution to national space projects. The fact that this value is significantly growing is seen from the growth of annual space budgets in India from Rs 2160 crores in 2002–03 to Rs 2997 crores in 2006–07.

Hand in hand with technology transfer process, an important step which the Indian space programme took was to involve user agencies in the government from the very beginning in the process of applications development and their validation. Specific initiatives were taken to build capacity among users for space applications. User's representatives were part of apex management structures that provided user viewpoint for planning future missions.

Although Indian space systems were mainly used by government organizations to begin with, the economic reforms adopted by the Government of India expanded the role of private industry in services related to telecommunications, television broadcasting and information generated from remote sensing from space. By this time, the Indian space programme has already evolved into operational phase establishing two major national satellite systems, capable of providing routine and reliable services to users, through Indian National Satellite (INSAT) series and Indian Remote Sensing Satellite (IRS) series. A substantial capability for launching satellites into earth orbits was also established[6].

In order to undertake marketing of space products and services developed by ISRO in global markets and also to foster the role of Indian industries in commercialization of space activities, the Government in 1992 approved formation of Antrix Corporation as a commercial arm under the Department of Space. Structured as a private limited company, Antrix is managed by a Board chaired by the Chairman of ISRO and participated by key leaders of ISRO's centres responsible for satellites, launch vehicles and applications and a few eminent leaders of industry in private sector. Antrix has also set a new model by adopting a very lean and efficient structure in terms of human resources strength and relying maximally on the infrastructure, facilities and expertise created in ISRO centres and Indian industry for implementing customers' programmes.

The business portfolio of Antrix is developed based on the heritage and track record of ISRO in different branches of space activity. This enabled Antrix to shape itself as a one-stop shop to cater to the needs of a variety of customers ranging from those who procured small components of a space system to large customers demanding a sophisticated satellite system delivered in orbit.

ISRO's fleet of remote sensing satellites has established a lead in the world in terms of service capabilities at competitive costs. Antrix chose to establish an alliance with one of the global leaders, namely EOSAT Corporation of USA, which later was transformed into Space Imaging Inc., for globally marketing remote sensing data. This cooperation brought about a synergy of complementary capabilities available from Antrix and its collaborator from the USA, resulting in a sizeable impact of securing about 20% of share in the addressable global market. An international network of ground stations emerged out of this alliance involving business/government entities in different countries to directly access data from IRS satellites. Currently, 20 ground stations are spread in the USA, Germany, Russia, China, UAE, Kazakhstan, Saudi Arabia, Thailand, Myanmar, Algeria and so on. The leadership established by the Indian space programme in earth observations applications has promoted a large number of value-adding enterprises in private sector. These enterprises integrated remote sensing data with emerging technologies and tools such as GIS, GPS and information processing and are catering to domestic and international markets in geospatial information applications.

Table 1. Status of space industry in commercial sector

Type	Value	Source
Infrastructure	**$28.7 Billion**	
Satellite manufacturing (commercial)	$2.30 B	SIA
Launch industry (commercial)	$1.20 B	FAA
Ground stations and equipment	$25.20 B	FAA
Infrastructure support industries	**$1.38 B**	
Internal research and development (IR&D)	$0.50 B	DoD
Insurance	$0.88 B	Via satellite
Satellite services	**$80.21B**	
Direct-to-home television	$46.00 B	In-Stat
Satellite radio	$0.81 B	XM, Sirius, WorldSpace
FSS	$9.80 B	SIA
MSS	$1.80 B	Northern Sky Research
GPS equipment and chipsets	$21.80 B	ABI Research
Space transportation services	$0.03 B	
Tourism (orbital)	$0.02 B	Space Adventures
Tourism (subtotal)	$0.01 B	The Economist

In the field of telecommunications and broadcasting, as mentioned, the policies adopted by Indian government on liberalization of economy drove the deregulation of telecommunications which expanded the role of private sector in telecommunications and broadcasting. A contract was made with INTELSAT, one of the largest satellite service providers in the world, to lease-out a part of capacity of INSAT-2E, over a period of ten years and worth a hundred million US dollars. This brought the recognition of maturity of Indian satellite technology by international standards. A satellite communications policy, which was adopted by the government, permitted uplinking of TV programmes to INSAT satellites by private service providers. The policy also permitted establishment and ownership of Indian satellite systems (for communication and broadcasting) by private sector companies[7]. At present the space infrastructure for services such as TV distribution, DTH and VSAT services are leased by Antrix from the capacity available from INSAT system, thus providing critical support to this economically and socially important sector. Antrix has also been playing role to procure capacity for unmet demands from international satellite operators on a temporary basis. It is noteworthy that already the size of the market for downstream services and for ground terminals are several times larger than investment into space segment, thus truly displaying the multiplier effect.

A recent development which is equally important is the establishment of an alliance between Antrix and the European satellite manufacturer EADS Astrium to jointly manufacture and market commercial communications satellites in the global market. Two satellite contracts are currently under execution for Europe under this framework, where a substantial level of Indian satellite technology is being offered to global market[8].

The space launch market is one of those which offer considerable challenge for entry and development due to restrictions placed by major markets like the USA on export of their satellites for launch. This industry is also subject to overcapacity and intense competition. Antrix made initial forays into this market by offering cost effective launch for small satellite systems in a piggyback mode. Satellites from Germany, Belgium, Korea, Indonesia and Argentina were successfully launched in this mode by PSLV. In 2007, a full-fledged commercial launch was performed by PSLV by carrying an Italian scientific satellite AGILE into a near equatorial orbit. As the capacity for launches by India will increase through new variants like GSLV-Mk III, there will be a greater scope for commerce in this segment. Future of space commerce globally is driven by many factors. Low cost access to space, geopolitical developments, international security environment, technological changes and ability to meet new and increasing demands for socioeconomic sectors contribute to new opportunities. India whose economy is growing at an impressive rate over past few years will experience greater needs for communications and information. This in turn will drive burgeoning needs for bandwidths to be delivered by satellites. Demand for new services such as mobile multimedia, positioning and navigation, disaster management, rural connectivity and security-related applications will create additional opportunities for commercial space activities. While exploring these new markets, Indian industry will possibly move towards owning satellites, either wholly or in strategic partnership with their customers in fields such as broadcasting. At the same time, Indian space enterprises will also seek to extend their services to other regions in collaboration with international players. There could be pursuit by Government of India to evolve an understanding with the USA to enable export of satellites from the USA for launch in Indian launch vehicles. Several such initiatives will demand expansion of capacity in commercial activities such as Antrix and other industries in India. Key to success in space commerce by India is the human capital created over the past decades, coupled with reliable performance and cost effectiveness of the systems. Effective use of these strengths can result in making India one of the significant sources and destination for space commerce.

Cost–benefit analysis

Need for cost benefit analysis

Space programmes in all space-faring nations are either in the public sector or in the private sector with government financial support. Government ownership or financial support for the private firms is necessary for the following reasons. First, the objectives of space programmes include not only achieving and maintaining technical excellence in the exploration and use of outer space and creating a strong industrial base in space-related activities but also in ensuring a country's independence in this area and maintaining national security. Second, investments in space activities are lumpy, involve long gestation periods and are risky. Hence, state support is needed at least in the experimental and development phases. Third, research and development expenditures in space technologies generate positive externalities in the form of spillovers and spin-off's, which accrue to the society as a whole. As an investment in the future, space technologies become an important tool of social and economic development. Fourth, the output basket of a space programme consists of a private goods, social goods, public goods and intangibles.

Social cost–benefit analysis framework is useful both for investment decisions in space activities and evaluation of costs and benefits of the programme to society. There is a general consensus among policy makers that any public or publicly funded project must meet the criterion of cost minimization or cost effectiveness. Regarding the benefit measurement, the approach depends on the nature of goods (market conditions and policy goals). In case of private

Table 2. Cost–benefit analysis framework

I Construction stage (at ISRO level)

Component	Criteria
INSAT system	Cost effectiveness
Earth observation system	Cost effectiveness, self-reliance
Launch vehicle	Cost effectiveness, self-reliance, spin-off benefits

II Exploitation stage (at user level)

Component	Outputs	Criteria
Broadcasting	Public good	Cost savings
	Social good	Social benefits
Telecommunications		
Remote area		Cost savings
Village phones, PCOs	Social good	Social benefits
Government networks	Public good	Cost savings
Private networks	Private good	Commercial benefits
		Cost savings
Meteorology		
Weather forecasts,		
Disaster management	Public good	Cost savings
		New/improved service
		Value of information
		Meteorologists' perceptions
Private uses	Private good	Actual and potential benefits
Earth observation		
Mapping, archival		Cost and time savings
Disaster management	Public good	Value of information
		Social benefits
Bioprospecting	Private good	Actual and potential benefits
Fishing zone advisories and other private uses		

good social consideration is not relevant and if the market is competitive, then the competitive market price reflects the benefit or the social value (see note 1). In the space sector, market price for launch services and some remote sensing services, deviate from their social costs because of government interventions for strategic, equity and other reasons. When the output is in the nature of a public good or intangible, the benefits have to be imputed because either the markets do not exist or even when they do exist, they do not reflect the social values (see note 2).

Measurement of social cost of each product is the first step. It conveys to the agency the social scarcity value of the product. Along with estimates of social benefits for different activities, the decision maker can decide whether production of a particular product is socially desirable or not, the extent of subsidy implicit in a price, and for the programme as a whole whether social benefits exceed or fall short of the social costs.

In view of the growing market potential, private entry and the need for ascertaining the economic costs of different space activities for inputs in decision making, the ISRO commissioned a study on the economic analysis of Indian space programme to Madras School of Economics in 2000. This report is now published in a book form[9]. This part of the article is based on the results of the above study. This economic analysis is broadly divided into two stages: (i) the construction stage (at ISRO level) and (ii) the exploitation stage (at the users' end) (see note 3). ISRO's outputs are generally intermediate inputs, which are used by the user agencies in producing the final product outcomes.

The output of space technology is a mixed basket of private good, public good and social good and therefore measurement of benefit is a complex exercise. The measurement of benefits of the satellite technology in the exploitation stage falls under three broad categories: (i) whether the technology is unique, (ii) whether the technology is a substitute to an existing technology, and (iii) whether the technology is complementary to an existing technology. In the second category, one can measure cost savings due to satellite technology in comparison with an existing technology. If the satellite technology is superior to the conventional technology, one has to estimate benefits attributable to the improved satellite technology. When satellite technology is used in conjunction with other technologies, one has to rely on a cost allocation or benefit sharing procedure or to rely on expert opinion to identify the costs and benefits attributable to a satellite technology.

A framework for the economic analysis of the space programme for construction stage and exploitation stage is summarized in Table 2.

The economic approach to space policy is illustrated with two examples. The first one deals with the economic costing of INSAT payloads and uses the cost estimates to find out the comparative advantage of India in the production of communication transponders (see chapter 4 in ref. 9). The second one deals with the measurement of costs and benefits of the Indian remote sensing programme.

Economic costing of INSAT communication payloads

As communication transponders are traded goods and there is an international market for the transponders, it is possible to assess the cost effectiveness of manufacture of these payloads by comparison with market prices. We need annualized capital cost and annual operating cost to estimate economic cost of transponders.

In the first instance, INSAT-2E, which is one of the advanced multi-purpose satellites of India launched on 3 April 1999 is taken as a case study to determine the cost effectiveness of the transponders. Later, the methodology is extended to INSAT-3C and 3E, two important communication satellites launched during 2002–03 timeframe.

INSAT-2E is the heaviest and technically advanced satellite of the five satellites in INSAT-2 series. It has both communication and meteorological payloads. The communication payloads consist of 10 low-power C-band zonal coverage transponders (32 WTWTA eirp 36 dbw) and 9 high-power C-band wide coverage transponders in 36 MHz units (60 W TWTA and eirp 36 dbw). The meteorological payloads consist of 1 Very High Resolution Radiometer (VHRR) and 1 Charge Coupled Device (CCD) camera. INSAT-2E was launched on 3 April 1999. It has an expected life of 12 years.

The procedure used for estimating annualized capital cost is as follows. First, identify the capital costs (book values) attributable to and apportionable to INSAT-2E. Second, classify INSAT-2E costs under (i) payload cost, (ii) platform cost, (iii) other spacecraft-related cost, and (iv) launch, insurance and transportation cost. Third, estimate the present value of capital expenditures as on 1 April 1999, assuming a discount rate of 12 per cent (see note 4). Fourth, allocate the present value of capital costs between communication and meteorological payloads. The payload costs are actual costs. The platform cost is both power dependent and mass dependent. Other spacecraft costs are allocated on the basis of the relative importance of communication and meteorological payloads in the sub-total of payload and platform costs. The launch, insurance and transportation costs are allocated on the basis of payload dry mass. Fifth, compute the present value of each payload assuming a life of 12 years and a discount rate of 12 per cent. Sixth, the annualized capital cost of each payload is obtained by dividing the present value of payload capital cost by its present value. This procedure establishes a methodology for allocating the costs amongst various transponders/payloads of a communication satellite and to arrive at the unit cost of the transponder.

The estimated annualized capital cost and operating costs for the low-power and high-power transponders are given in Table 3.

In order to assess India's comparative advantage in the production of zonal beam and wide beam transponders we have to estimate the quoted annual lease charges for INSAT-2E low power and high power transponders. We make the following assumptions: (i) the lease period is 12 years, (ii) the provision of 10% spare margin; (iii) the annual operating cost of Rs 0.096 crore increases at the rate of 12 per cent per annum; (iv) the exchange rate 1 US $ = Rs 42, and (v) the dollar discount rate is 7.5 per cent (see Note 5). The computations are given in Table 4.

The comparable long-term non-preemptible C-band 36 dbw 36 MHz unit transponder quoted lease charges for zonal beam coverage in the global market in 1999–2000 varied between US$ 1.3 million for Thaicom and US$ 1.7 million for Loral; the corresponding variation for wide beam zonal coverage transponder was between US $1.7 million for Lyngemark Satellite-1 and US$ 2.2 million for Pan Am Sat.

It is evident from the above that the estimated lease charge quoted for INSAT-2E low power transponder is 85.2 per cent of the charge for Thaicom zonal beam transponder. The quoted lease charge for INSAT-2E high power transponder is 73 per cent of the charge for wide beam Lyngemark Satellite-1. The cost advantage of INSAT-2E communication transponders will be higher if we assume a discount rate of 10 per cent instead of 12 per cent. The estimated quoted lease charges based on 10 per cent rupee discount rate and 5.5 per cent dollar discount rates are US$ 0.973 million for INSAT-2E low power transponder and US$ 1.094 million for INSAT-2E high power transponder. Thus, India possesses comparative advantage in the manufacture of communication payloads.

The analysis was further extended to INSAT-3C and 3E satellites launched on 24 January 2002 and 28 September 2003 respectively. These are slightly heavier, but unlike INSAT-2E (which has both communication and meteorology payloads), they have only communication transponders payloads. In terms of equivalent of C-band 36 MHz, both have 36 C-band/Ext C-band transponders. Economic cost analysis has indicated that the annual lease charges of these transponders would work out to be US$ 0.67 million with 12% cost of capital and 7.5% discount rate, and

Table 3. Economic costs of communication payloads in INSAT-2E (Rs crore)

Payload	Annualized capital cost	Annual operating cost	Total cost
Low power transponder	4.354	0.096	4.450
High power transponder	4.897	0.096	4.993

Table 4. Estimation of annual non-preemptible lease charges for INSAT-2E transponders

Item	Low power	High power
(1) Present value of capital cost* (Rs crore)	30.200	33.966
(2) Present value of operating cost (Rs crore)	1.152	1.152
(3) (1) + (2) (Rs crore)	31.352	35.118
(4) Adjustment for 10% spare margin (Rs crore)	34.836	39.020
(5) Value in million US dollars	8.294	9.290
(6) Constant annual lease charge for 12 years when discounted at the rate of 7.5% in million US dollars	0.997	1.117
(7) Annual lease charge with 12% cost of capital and 7.5% discount rate (M$)	1.108	1.241
(8) Annual lease charges with 10% cost of capital and 5.5% discount rate (M$)	0.876	0.985

*Annualized capital cost times the present value of output of 6.9363.
(Though Union Planning Commission uses a discount rate of 12% for public investment projects, as the interest rate has fallen in recent years, a sensitivity analysis with 10% cost of capital and 5.5% discount rate was also carried out and the result is tabulated in (8).)

US$ 0.59 million if we take 10% cost of capital and 5.5% discount rate. This exercise has reconfirmed the comparative advantage India has in the manufacture of communication transponders.

Costs and benefits of Indian remote sensing

Earth observation satellite sensors receive electromagnetic radiation reflected or emitted from the surface of the earth and deliver it in a digital form to ground stations at regular intervals. The digital capture of raw satellite transmitted data is convenient for storage and easy retrieval, and amenable for corrections, refinements and value addition. The advantages of remote sensing data are synoptic coverage, multi-spectral capability and multi-temporal capability.

Economic analysis of costs and benefits of remote sensing (RS) programme in India is at an early stage. The existing information base on capital costs of the IRS programme is based on book values. We need a time pattern of investment outlays to estimate capital expenditure on a satellite at constant prices. The payload configuration of each remote sensing satellite is unique and is designed to meet the needs of a space agency/country. As a result, it is difficult to compare a particular IRS satellite with a foreign satellite. Further, an assessment of the comparative advantage of an IRS satellite with a foreign satellite is difficult because (i) the relevant cost data is not in the public domain, and (ii) there does not exist a global competitive market for remote sensing satellites. Therefore, a comparison of costs of remote sensing satellites is rather difficult.

However, one can get an idea about the cost-efficiency of IRS satellites by comparing the costs with a few contemporary satellites of similar capability though not of the same capability. The cost of IRS-1D satellite, launched in 1997 is about US$ 50 million. IRS-1D has a panchromatic camera of 5.8 m resolution, a multi-spectral camera of 23 m resolution and a wide field sensor of 180 m resolution. The satellites launched in the same time frame with comparable characteristics are SPOT-4 (French) and LANDSAT-7 (USA), both launched in 1998. Their costs are quoted around US$ 500 million. The LANDSAT-7 has a panchromatic camera of 15 m resolution and a multi-spectral camera of 30 m resolution. SPOT-4 has a panchromatic camera of 10 m resolution and a multi-spectral camera of 20 m resolution. One can see the resolution specification of IRS-1D is superior to both SPOT-4 and LANDSAT-7 but yet the cost of IRS-1D is unbelievably lower than that of SPOT-4 and LANDSAT-7. One of the major factors for the cost advantage of IRS satellites is the lower engineering cost. In remote sensing satellite, the non-recurring engineering costs associated with design, development and testing (manpower intensive) are very high and this is probably one reason why remote sensing satellites elsewhere in the world are expensive. We need more cost information for the foreign satellites to understand the sources and extent of the cost advantage of IRS satellites.

Regarding the measurement of benefits, as mentioned earlier, the output basket of the IRS programme consists of a mixed basket of private, social and public goods and intangibles. As of now, most applications based on the IRS data have been in government projects and these projects have objectives such as development of backward areas, equity and generation of information base for evaluation and monitoring of natural resources. Ideally, in a social cost benefit analysis, the benefits should be measured in terms of outcomes, i.e. the benefits occurring to consumers (increase in utility), producers (increase in profit) or society as a whole (increase in social welfare). Most available data are in the form of intermediate inputs or outputs, and to understand the 'last mile problem' in the delivery of public services, there is a need for measuring the outcomes by conducting specially designed surveys using social cost benefit analysis framework .

There are a few attempts to measure the costs and benefits of the IRS programme. Gupta and Jayaraman[10] used the cost effectiveness approach and estimated the benefits in the form of cost savings in mapping using remote sensing techniques for the period 1980–96 at Rs 515 crore. Rajan *et al.*[11] relied largely on a questionnaire survey to assess the potential benefits of the use of remote sensing technology in business applications. They estimated the potential economic benefit of remote sensing in agriculture, based on case studies, in the range of Rs 3000–6000 a year. The approach followed in Rao and Sankar[12] involves first, estimating the cumulative expenditure on the IRS programme in book values till 31 March 2001, followed by estimating the investment in operational missions and expenditures on data reception, processing and applications of the IRS programme. Thirdly, the direct benefits in the form of revenue realization are estimated. Fourthly, the quantifiable economic benefits based on case studies, user feedback and other secondary sources are measured followed by the list of the nature of social benefits/advantages of adopting the remote sensing approach in formulation of developmental projects. Next, after highlighting the technological achievements, it indicates the areas for fruitful research using the IRS data to measure the economic value of the information as the final step.

The total expenditure in remote sensing programme in book values, incurred from the beginning till 31 March 2001 (when the study on economic analysis of Indian space programme was undertaken) was Rs 2129.68 crore. Of this, the expenditure on operational missions was Rs 1008.48 crore, which includes the spacecrafts, launch services and operating costs. The expenditure incurred on data reception processing and application was Rs 554.07 crore. The revenue from sale of National Remote Sensing Agency data was Rs 160 crore and the revenue from sale of IRS services/products by ANTRIX Corporation was about Rs 50 crore.

The economic benefits accruing to society are estimated from case studies. In Rajiv Gandhi National Drinking Water Technology Mission, the benefits of groundwater prospect maps arise due to higher success rate of finding water 80–95 per cent compared with 40–50 per cent achieved using conventional methods. The resulting cost savings due to increase in the success rate in 5 states was about Rs 256 crore. The potential benefit to the country in the long-run is estimated between Rs 500 and 800 crore. Apart from this cost saving, the other benefits are speedy implementation of the project and generation of databases which can be used as baseline for future expansion/modification of the development projects.

The National Wasteland Inventory Project based on remote sensing data gives for the first time a thirteen-fold classification of wastelands. The information generated in the preparation of wasteland maps has resulted in the launch of many development programmes for reclamation or/and better utilization of wastelands. The potential productivity gain from the use of wastelands is more than Rs 2000 crore. The Integrated Mission for Sustainable Development uses satellite data to derive information on land use/land cover, soils, groundwater, geomorphology, slope, information on rainfall, aridity and socio-economic profile of the local area and integrating all the data using geographic information system and involving people's participation. The long-run economic benefits in the form of increase in gross income could be between Rs 1300 crore and Rs 2600 crore.

The Forest Survey of India carry out biennial forest cover mapping using satellite data. District-wise maps are also being prepared to monitor the changing scenario in forest cover. The State of Forest Report gives for each state details on land use under a nine-fold classification. Preparation of Forest Working Plan using inputs derived from remote sensing techniques requires only about 1/3 of the time and 1/6 of the cost compared with the conventional methods. The potential cost saving to the country in the long-run is estimated around Rs 1186 crore. Identification of potential fishing zones using remote sensing techniques gives the fishermen the higher probability of going to the right place for fish catch and thereby avoiding trips in non-potential fishery zone area. The potential cost saving could be about 1635 crore.

Use of remote sensing technology in preparation of urban area perspective/development plans for cities results in both time and cost savings. If such plans are prepared for all cities and towns, the potential cost savings alone could be around Rs 1800 crore.

It is true that the potential savings reported above occurs over time. Further, the savings/benefits are extrapolated from the limited information available. The samples considered may not be representative due to selectivity bias. Further, the potential benefits could be realized only if right institutional structures and policies are in place. Nevertheless, as the magnitudes of estimated potential benefits are so large compared with the actual costs of the IRS programme, it is reasonable to assume that the economic benefits alone would be higher than the costs of the operational missions of the IRS programme.

Many applications of remote sensing techniques yield benefits, which are in the nature of public goods. Such benefits arise from archival value of IRS data, biodiversity characterization, coastal zone mapping, disaster management and periodical monitoring of the status of forest cover, coastal zones, water pollution and so on. The remote sensing techniques have become an important tool for developmental planning in India. These techniques also help policy makers to meet statutory and legal requirements in India and also comply with India's commitment to building information systems under various multilateral environmental and other agreements.

A detailed cost–benefit analysis of the Indian launch vehicle programme has been carried out as a part of the studies on economics of Indian space programme by Sankar[9]. Even though specific details about the developmental costs of all the foreign launch vehicles are not available, the development cost of India's PSLV and GSLV is observed to be in the range of US$ 1.3–1.5 billion as compared to about US $ 4 billion for the European

Ariane 1 to 4, though there are some capacity variations in these systems.

Conclusion

ISRO has been able to achieve the goals of providing space infrastructure for socio-economic development and self-reliance in production and launch of the satellites. ISRO's organizational structure, its mission-mode approach and its early preparatory initiatives to tap emerging market opportunities will enable her to meet the challenges of liberalization and privatization. ISRO products are being accepted in the world market. It is remarkable that the physical targets have been achieved in a cost effective way. The comparative cost advantage with respect to communication payloads has been demonstrated. More cost information is needed on the foreign satellite to understand the source and extent of the cost advantage of IRS satellites. Thus, the Indian space programme is set to play a more crucial role in India's national development and also make a significant impact in the global scene in the years to come.

Notes

1. A private good possesses two characteristics, namely, rivalry in consumption and excludability.
2. A public good possesses two features, namely, non-rivalry and non-excludability.
3. Bramshill Consultancy Limited (UK) in its 'Impact Assessment' of European Space Agency Programme adopted the two-stage approach. See European Space Agency (1999).
4. The Union Planning Commission used a discount rate of 12 per cent for public investment projects. As the interest rate has fallen in recent years, 10 per cent would be more realistic now. The cost exercise was also done using a discount rate of 10 per cent.
5. The dollar discount rate is lower than the rupee discount rate mainly because the average annual inflation rate is lower in the US than in India.

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