INTERNATIONAL COOPERATION IN SPACE TECHNOLOGY: AN ABSTRACTION WITH FUZZY LOGIC ANALYSIS

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Abstract – India’s cooperation with International Space faring nations has a long legacy of cooperation. As India moves towards realizing its space aspirations, its co-operation for outreach and capacity building with international partners will increase. This cooperation is reflected in all spheres of national development, security and space exploration of both the primary as well as partnering nation. Policy considerations and directives acts as a key to define the future course of action for such cooperation. The paper attempts to present parameters for evaluating policy options of India’s international space cooperation with an example of India-Israel space cooperation. The paper uses fuzzy logic modeling for scoring parametric valuation for pursuing cooperation. This valuation can assist in making feasibility analysis for a collaborative mission or project with a partnering nation. These parameters include the erstwhile and ongoing collaborations and cooperation, economics of the collaborative project, security considerations, technical considerations & space ambitions. The output delivers aggregated value for ‘checks and balance’ derivatives for informed decision making.

1. INTRODUCTION

Space technology and space based data/services have become relevant for studying spatial and temporal pattern of resources in the context of burdening demand of growing populations. To enhance co-existence and better management of resources, countries are collaborating for space technology, space infrastructure sharing, space data distribution and utilization for societal benefits. ‘Space’ forms a trans-national dimension for international cooperation and goodwill generation. International collaborations in space technologies are focused on scientific and technological factors along with political, economic and cultural aspects, which eventually lead to strategic long standing partnership or relation. Though literature exists about the cooperation and policies describing how successful they have been, very few indicate any logical quantification in this regard. This paper identifies inter-relationship of prominent Indian space collaborations with International communities along with their respective components and their relevance (section-2). An attempt is made to indicate a logical qualitative analysis (in section-3) onwards assessing suitability of International space cooperation with an example.

- Transfer of Technology in energizing sectors/ application, which otherwise would have taken several years to develop.
- Use of common space-infrastructures and sharing of space based data for resource management and societal benefits.
- National security agreement towards space security among the nations.
- Enhanced research in science, technology, engineering with more number of students / professionals and its impact on education and economy.
- Better understanding of planetary exploration science and technology for information and evaluation of universe (impacts on Astro-Physics)

The prominent space faring nations are USA, Russia, Europe, France, Japan, China, Canada, UK and India. Up until a decade back India was the only developing nation developing space technology. More nations have joined this group in the last decade. In early years of the 21st century, policy emphasis lead towards conception of thematic satellites for geophysical products as well thematic data sharing in collaborative mode between nations. Space data sharing policy, product generation and sharing, quality measurement methods etc evolved with increasing international sharing of data and technology. In this regard leading role is played by NASA, ESA, CNES, JAXA, ISRO and other international space forums. On the other hand, technological viability for smaller and cheaper alternatives with micro / nano / pico satellites made space technology more affordable in recent times. Several MOUs have been signed between different nations for development of satellites; launch services and data products sharing. The world is moving towards a new era of multi-level and multi-dimensional space based management.

2. SPACE TECHNOLOGY CO-OPERATION FOR INDIA

Space program of a country is amicably interlinked with three factors – i) Science & engineering, ii) Commerce and iii) Security. Establishment of a long term space science/engineering and exploration efforts are primarily discouraged by high cost of space technology programs and nurturing of competent human resources that needs to be built over a substantial period of time. International co-operation in space technology is rewarding for a set of nations to achieve common space science objectives in the following areas:

- Stronger space research program leading to the development of specialized technological capability.

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2.1 Collaboration in Space and Ground Segment

India has adopted a strong passion towards development of space technology and missions. It has international cooperation components in many of its missions from the launch of Rohini and Aryabhata in the early days to the recent Chandrayan-I and Mangalyan mission (https://www.isro.gov.in/launchers/list-of-pslv-launches). The major component of space cooperation between ISRO and international community are in the fields of -

- Launch vehicle and launch service.
- Payloads and sensors - scientific and civilian mission.
- Space communications and infrastructure.
- Tracking and data reception facilities.

ISRO has formal agreements / MOUs with many nations and organizations, namely include Argentina, Australia, Brazil, Brunei, Darussalam, Bulgaria, Canada, Chile, Egypt, European Center for Medium Range Weather Forecasts, European Organization for the exploitation of Meteorological Satellites, EUMETASAT, European Space Agency, France, Germany, Spain, Sweden, Syria, Thailand, Netherlands, Ukraine, UK, USA and Venezuela. This proves the growing worthiness and benefits of International space cooperation (unoosa.org 2018) as a practice and policy. Major international space collaborations between India along with respective components are compiled from open source information (table 1).

<table>
<thead>
<tr>
<th>Element</th>
<th>Components</th>
<th>Mission</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lift vehicle</td>
<td>Launch</td>
<td>Aryabhata &amp; Rohini</td>
<td>Russia, USA</td>
</tr>
<tr>
<td>Heavy launch vehicle</td>
<td>Lift vehicle and launch service</td>
<td>Arian for 18 Geostationary satellite</td>
<td>France</td>
</tr>
<tr>
<td>Light launch vehicle</td>
<td>Lift vehicle and launch service (PSLV)</td>
<td>SPOT 6, 7</td>
<td>India</td>
</tr>
<tr>
<td>Engine</td>
<td>Liquid engine technology in PSLV Second stage</td>
<td>PSLV</td>
<td>France</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engine</th>
<th>KVD-1 Cryogenic engine</th>
<th>GSLV upper stage</th>
<th>Russia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric ion propulsion engine (EIP)</td>
<td>South Asian Satellite for SAARC countries</td>
<td>Japan</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Collaborations for components for Launch vehicles and Launch Services.

Green color indicate that India is providing service and blue color indicate that India receives service / technology from international community, yellow color indicates joint development. Pink color indicates short term and lavender color indicates medium to long term cooperation.

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<tr>
<th>Element</th>
<th>Components</th>
<th>Mission</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>SAPHIR and SCARAB</td>
<td>Megha Tropiques</td>
<td>France</td>
</tr>
<tr>
<td></td>
<td>MADRAS</td>
<td></td>
<td>France &amp; India</td>
</tr>
<tr>
<td></td>
<td>ALTIKA, ARGOS, on board radiometer</td>
<td>SARAL</td>
<td>France &amp; India</td>
</tr>
<tr>
<td>L band (NASA), S band (INDIA)</td>
<td>NISAR</td>
<td></td>
<td>USA &amp; India</td>
</tr>
<tr>
<td>X Ray astronomy mission</td>
<td></td>
<td></td>
<td>Russia</td>
</tr>
<tr>
<td>ROSA</td>
<td>Oceansat-2</td>
<td></td>
<td>Italy</td>
</tr>
<tr>
<td>ARGOS</td>
<td>Oceansat-3</td>
<td></td>
<td>France</td>
</tr>
<tr>
<td>Meteorological sensor, Transponder, data reception</td>
<td>South Asian satellite</td>
<td>[\text{India}]</td>
<td></td>
</tr>
<tr>
<td>Science Payload</td>
<td>Spectrometer, SIR-2, SARA, Radome, MiniSAR, Moon mineralogy mapper</td>
<td>Chandrayaan-1 X-ray, Manson, USA</td>
<td>ESA(UK, Germany, Sweden, Bulgaria,) USA</td>
</tr>
<tr>
<td>Deep Space Network</td>
<td></td>
<td></td>
<td>USA</td>
</tr>
<tr>
<td>Ultraviolet imaging telescope</td>
<td>Astrosat</td>
<td></td>
<td>Canada</td>
</tr>
<tr>
<td>X-ray astronomy Instrument</td>
<td>Coronas photon</td>
<td></td>
<td>India</td>
</tr>
<tr>
<td>Space X ray observation</td>
<td>X ray instrument</td>
<td></td>
<td>Japan</td>
</tr>
</tbody>
</table>

Table 2. Collaborations for development / contributions of Payload / Sensors

Most common International cooperation happens in the form of MOU in telemetry and tracking where restricted ground access in other countries becomes accessible for tracking (Table-3).
2.2 Space Data sharing with International Communities

- India is playing a leading role in Sentinel Asia initiative under International disaster charter operations to support disaster management in the Asia-Pacific region applying remote sensing and Web-GIS technologies.
- Megha-Tropehiques processed data from ROSA and SAPHIR sensor are shared with international users for study of the tropical atmosphere / climatic conditions.
- Astrosat SARAL (ALTICA and ARGOS) data is shared with international community for studying ocean from space altimetry.
- Information generated using Oceansat-2 and Scatterometer is made available globally in near-real time for global applications through an arrangement with Eumetsat.
- ISRO is in cooperation with USGS for Landsat 7/8 and Resourcesat-2 data sharing, with NASA for Scatsat Rapidsat data utilization and with ESA for IRS, Sentinel data sharing, and with Canada for microwave data sharing (eas.europa.eu).
- Antrix and NRSC signed MOUs with different international space agencies for receiving their satellite data using Indian ground station and providing Indian satellite data to International community.
- Antrix is in collaboration to sell IRS, CARTOSAT, data in Australia and African countries. Such cooperation is paving the way for experimenting with new sensors and working jointly. India has launched more than 50 satellites for more than 20 different nations by 2018, including African & Asian countries and developed countries (USA, France, Canada and Europe). The share ISRO’s income generated from commercial satellite launch towards Indian economy has increased significantly.

2.3 Space Utilization - India’s involvement

India is in active cooperation with space forum of other countries like GEOS, ATRFAS, UN-ESCAT etc. for natural resource management and monitoring, disaster management and capacity building. Under UN-ESCAP program, India is providing technical support for development of Draught monitoring system using satellite data with field data collection and data viewing at Bhurban through an exclusive access. ISRO also provide training and hand holding for data processing and analysis. India and EU have a established cooperation for space research and technology. This India-EU space cooperation has multitude of facets that have been agreed upon (esa.int). These include space security, space situational awareness, multi object tracking radar etc.

2.4 Collaboration in Capacity Building

Indian cooperation with international and regional countries is strongly linked with capacity building. Institute of Remote Sensing (IRS) and UN affiliated Centre for Space Science and Technology Education in Asia and Pacific (CSSSTEAP) involves in capacity building of 55 countries of east, south-east Asia, central Asia, Pacific. It offers short term training courses and 9 months and PG diploma on space technology application about remote sensing and GIS, SATCOM, SATMET, Space Science and GNSS. IRS also offers 8 weeks course on RS and GIS under Indian Technical Economic Cooperation (ITEC) sponsored by MEA. More than 1600 officials from 93 countries are offered training by IRS and CSSSTEAP (http://www.csssteap.org/). To assess the impact of International Space cooperation on overall education / research of science and engineering at India, relevant data is not available (scholarly citation impact is negligible). The joint Civil Space Working group (between USA and India) discussed India’s participation in NASA led GLOBE education program (Global Learning and Observations to Benefit the Environment). However, the number of enrollments of schools in India is less encouraging. In all the above mentioned areas of cooperation, the relevant policy documents plays a very important role in defining the course of action and its future success, which needs to be assessed.

3. MODELING INTERNATIONAL SPACE COOPERATION WITH FUZZY LOGIC

Policy on international space cooperation can be accessed through measuring the mix of uncertainties that enables, hastens, prolongs, delays or causes failure of international space cooperation. At present international space co-operations are judged by mode of operation between participating countries, transaction cost to achieve mission elements or technology, and analyzing past instances of interaction / cooperation between participating countries. Most of the time a technological component as well as high development cost is involved with space co-operation. This factor triggers the requirement of the techno-political analysis of space cooperation for a better understanding of the interplay of parameters. Policy imperatives for domestic and global influence in the arena of international space cooperation can be modeled. The cooperation in terms of economic benefit, influencing regional and global strategic interests, enhancing national prestige, domestic economic well being can be measured through such modeling. This paper develops a Fuzzy Logic model for understanding international cooperation on space technology and its indication towards achieving success using these parameters (Fig. 1).
It has been applied to test the feasibility of collaboration between India and Israel. Modeling has been created using Fuzzy Logic in Matlab.

Fuzzy models convert crisp values into fuzzy values to provide an indication of variables that cannot give discrete output. It is helpful in qualitative assessment of variables that answer queries on subjective nature of assessments. The collaboration scenario is captured through technical, cooperative and policy related parameters that influence the deal (Juan Miguel et al).

Some of the variables are direct parameter which directly affect the quality of the cooperation (example: Cost). Few of them are derived parameters using more than one parameter, statistically or by expert opinion. A parameter sometimes acts as a control variable indicating its overriding powers on other parameters (political willingness, national security etc). The condition that defines the relationship is based on the type of variables and their inter-relationship.

Table 4. Facts & Assumptions for India Israel Cooperation.

<table>
<thead>
<tr>
<th>India</th>
<th>Israel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch and other components cost approximately 30% less than international agencies.</td>
<td>Space technology components costs much higher than India most of the time.</td>
</tr>
<tr>
<td>Indigenous development in launch vehicle, space port and other infrastructure / asset base</td>
<td>Indigenous development in advanced optical, SAR sensors and techniques,</td>
</tr>
<tr>
<td>Leader in launching LEO satellites, providing remote sensing data in civilian applications</td>
<td>Leader in defence satellites with advanced sensors, expertise in miniaturization of hardware component for mission, UAV</td>
</tr>
<tr>
<td>Aiming at becoming a major space power with increased market share for space launch.</td>
<td>Aiming at increased market share for sensor technology and Mission hardware</td>
</tr>
<tr>
<td>Primary focus area is development and benefit of the society</td>
<td>Primary focus area is defence and national security.</td>
</tr>
<tr>
<td>Launched Israeli Satellite TESSAR in 2007</td>
<td>Sensor contribution for Indian satellite RISAT.</td>
</tr>
<tr>
<td>Inter planetary missions (Moon and Mars mission) achieved with lower cost, indicating technology demonstration and enhanced national pride.</td>
<td>Scope of future cooperation in interplanetary joint mission by developing sensors like ultra-violet, x-ray imaging instrument and other sensors suitable for astrophysics application.</td>
</tr>
<tr>
<td>Indian manufacturing can reduce the cost of satellite systems</td>
<td>Extended R&amp;D can gain pace with collaboration due to limited budgets.</td>
</tr>
<tr>
<td>Invested funds for joint industrial development, including in space technology.</td>
<td></td>
</tr>
<tr>
<td>Both the countries can increase their market share by combining the strength and expertise in launch vehicle, launch service (India and advanced sensors (Israel)).</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Fuzzy logic design and modeling:
An attempt has been made to model such complex scenario and interwoven parameters with Fuzzy Logic to get a better understanding of policy. The parameters considered are in synchronization with the assumptions mentioned at table 4, which were felt important by the subject expert on policy.

3.3 Parameters defining collaboration policy
The parameters indicating success in space cooperation are mainly categorized as:
- Technical Parameters, through assessment of cost, schedule/time, performance/efficiency, safety, risk.
- Policy Parameters includes national pride, security, regional influence, domestic economy, maintain technicality.
- Cooperative Parameters is constituted by indicating long term or short term collaboration.

In this example understandable conditions for joint missions, where advanced sensors and data processing services
provided by Israel, has been enlisted. Launch vehicle, launch services along with other infrastructures are provided by India.

Table 5. Summarizes the parameters with their indicative meaning

A Fuzzy cognitive map in Fig. 4 is depicting the inter-relationship of different parameters/ variable with positive and negative indicators. Red Line indicates negative relation between affected and causal variables; Blue Line indicates positive relationship between affected and causal variables.

Figure 4: Cognition Model of Inter-relationship of parameters

A fuzzy set is defined by a value that varies between 0 (lowest or false) and 1 (highest or true), which assigns the membership function to each element in the set (Wang et all). The shape of the membership function can be linear (triangular or trapezoidal) or non-linear (Gaussian, Sigmoidal, Generalised Bell, Gama etc) depending on the nature of the system. To implement these functions an expert’s opinion is associated in the form weighted values to the variables in the set. Performance indicators (Table 5) of a space cooperation policy are associated with indicated membership function. Weighted gradations of different parameters (Table 6 & 7) were made while keeping in mind the assumptions as per table 4.

Table 6 Weightage of parameters (Source Arias et al, 2011)

The weighted values are then graded according to range to quality sections like B, B+, A, A+, A++.

Table 7 Gradation of Parameters

Fuzzy Cognition Mapping Matrix (Fig 5a), shows that if ‘cost’ and ‘performance’ measures are ideal (value <=0.5), involvement for longer ‘time’ becomes best suited for long term acquisitions. If ‘economic’ capability and ‘efficiency’ is high, chances of ‘collaboration’ (instead of mere acquisitions) (5b) increases substantially.

3.4. Fuzzy rule-sets and output

Relations between parameters can be defined using Fuzzy inference rules. Mamdani Min-Max approach is adopted here to
infer the degree of membership (Wang 2015 et all). Examples of rules are -

Using IF-THEN-ELSE Rules

IF input Cost_Vatiable is Less AND
Time_Vatiable is Less AND
Performance_value is More THEN
Result Output is (Defuzzification) High.

IF Cost_Vatiable is More AND
Time_Vatiable is Less AND
Performance_value is LESS THEN
Result Output is (Defuzzification) Medium.

IF Cost_Vatiable is More AND
Time_Vatiable is More AND
Performance_value is LESS THEN
Result is (Defuzzification) Low.

Implementing the rules through Fuzzy Models we can test and derive at the high output values for different inputs. Cost-Time-Performance output indicates the inter-relation of outputs. Cost-Time and Performance (Fig 6). If the cost is on higher side, the output value reduces (17.6%) from the current indicated value (75.5%). The best combination is when the lowest projected per-partner costs, time scale values are lower and the performance value is on the higher side (Fig 6).

Figure 6. Cost-Time-Performance Fuzzy Model (red line moving towards right side indicates higher value)

In the case of acquiring RISAT satellite, cost value was high, time was low and performance is on the higher side. Though it is far from ideal condition (low cost, time and high performance), India’s procurement with security considerations overruled other factors. Such decision is often subject to policy and political or security considerations and are not always based on ideal case (Fig 5). Similar concept is implemented for deriving the output of Policy and Cooperative parameters using weighted values in fuzzy model. The outputs of Technical, policy and Cooperative models are used to derive final output in this hierarchical fuzzy model for assessing ideal condition for India Israel cooperation (Fig 6).

CONCLUSION

Fuzzy modeling for assessing space cooperation is a novel approach, which has the potential to assess different interplaying parameters individually and as a whole for higher and effective decision making policy. As per the output model the success of India Israel cooperation increases the chances of success if policy implementation supports the individual parameters. For India-Israel space cooperation parameters related to policy plays a crucial role and sometimes acts as a control variable. It may be inferred that the cost of production and research can be brought down by collaborative project between both the nations by contributing in respective areas of expertise. This model has a potential to be implemented for other areas of space cooperation with various nations to understand the inherent strength and weakness.

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