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.

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 exp[1]loration 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.
- 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.

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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 Aryabhatta 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).

Element	**Components**	**Mission**	**Country**
Lift vehicle	Launch	Aryabhatta & Rohini	Russia, USA
Heavy launch vehicle	Lift vehicle and launch service	Ariane for 18 Geostationary satellite	France
		GSLV, GSAT for GLONASS	India
Light launch vehicle	Lift vehicle and launch service (PSLV)	SPOT 6, 7	India
		TECSAR	India
		Small satellites	Europe (Astriam)
		Megha Tropiques	France
		Saral Altika	France
		Cubesat	Taiwan
		NISAR	India
		YouthSat	Russia
		Nanosatellite constellation AISSAT 1 & 2	Norway
	GSAT 9 and launch service	South Asian Satellite	India
Engine	Liquid engine technology in PSLV Second stage	PSLV	France
Engine	KVD-1 Cryogenic engine	GSLV upper stage	Russia
	Electric ion propulsion engine (EIP)	South Asian Satellite for SAARC countries	Japan

Table-1. Collaboration 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.

Element	**Components**	**Mission**	**Country**
Sensors	SAPHIR and SCARAB	Megha Tropiques	France
	MADRAS		France & India
	ALTIKA, ARGOS, on board radiometer	SARAL	France & India
	L band (NASA), S band (INDIA)	NISAR	USA & India
	X Ray astronomy mission	Coronas Photon	Russia
	ROSA	Oceansat-2	Italy
	ARGOS	Oceansat-3	France
	Meteorological sensor, Transponder, data reception	South Asian satellite	India
Science Payload	Spectrometer, SIR-2, SARA, Radome, MiniSAR, Moon mineralogy mapper	Chandrayaan-1 X-ray.	ESA(UK, Germany, Sweden, Bulgaria,) USA
	Deep Space Network	Mangalyan	USA
	Ultraviolet imaging telescope	Astrosat	Canada
	X-ray astronomy Instrument	Coronas Photon	India
	Space X ray observation	X ray instrument	Japan

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).

Element	Components	Mission	Country
Telemetry & tracking	Deep space network for MOM launch monitoring	Mars Mission-	USA
	Ground station, Antenna	Chandrayaan-1	Russia
	Ground station & data reception	Different missions of India	Brunei, Indonesi a
	Ground station & antenna	GLONASS Ground station	Russia & India
Satellite communicati on	Satellite telecommunicati on experiment	Tech. Transfer to develop own communicatio n satellite	Germany
Space based power exchange	Ground station\ antenna	Demonstration	USA
Navigation		GLONASS	India
Human Space Flight	Flight for Cosmonaut onboard	Salyut-7	Russia

Table-3 Cooperation in ground segment and other areas

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-Trophiques processed data from ROSA and SAPHIR sensor are shared with international users for study of the tropical atmosphere / climatic conditions.
- Astrosat SARAL (ALTIKA 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 (eeas.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 Bhuvan 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 (IIRS) and UN affiliated Centre for Space Science and Technology Education in Asia and Pacific (CSSTEAP) 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. IIRS 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 IIRS and CSSTEAP (http://www.cssteap.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).

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Fig. 1. Block Diagram of International Space cooperation

3.1 India-Israel cooperation framework: An Example

There are two types of partners in any cooperation model. 'Primary' nation initiates / seeks the cooperation and the 'Partner' nation provides technology, mission element or services. India-Israel cooperation for RISAT (Blarel *et all*) mission has been studied with the generally acknowledged and accepted notions of benefit to both nations in the context of this model. India is considered as the 'Primary nation' and Israel is the 'Partner nation'. Underlying assumptions about India and Israel (table-4) need to get translated into a calculable matrix of parameters.

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

Table 4. Facts & Assumptions for India Israel Cooperation.

Green – Cost related parameters, Pink - Policy parameters, Blue - Technical efficiency/capability related parameters, Lavender-Combination of more than one parameter, Yellow- Scope for joint development.

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.

It has been applied to test the feasibility of collaboration between India and Israel. Modeling has been created using Fuzzy Logic in Matlab.

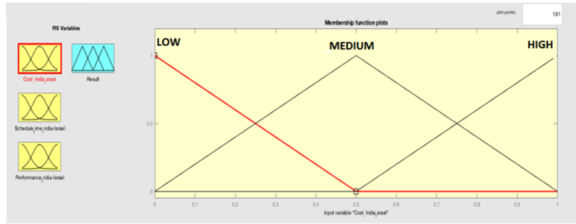

Figure 2 Fuzzy Concept & Membership Function

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 all*).

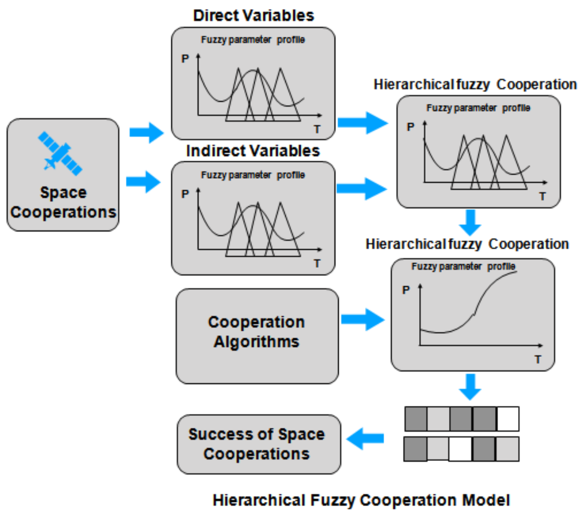

Fig.-3 Flow chart of Fuzzy Model implemented for assessment of space cooperation.

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.

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 understanding favorable 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.

SL no	Parameter	Indication / Meaning
Technical Parameter		
1	Cost effectiveness	Incurred by each partnering nation for proposed mission
2	Time frame and schedule	shortest time for receiving mission component/technology or completion of a joint project
3	Performance & Technical Capability	Effectiveness of mission elements or project.
Cooperation Parameters		
4.	Short Term Acquisition	Purchase of component that has limited life span
5.	Long Term Acquisitions	Purchase of components that have long service life
6.	Collaborations with other nations	These are collaborative projects that have taken place or can take place based on efficacy of favoring conditions
Policy Parameters		
7.	Economic Capability	The economic capability of a nation to take space related developmental activities
8.	Technical Capability	Technical capability of partnering nation to take an endeavor for space missions
9.	Domestic and international influence	of policy makers to make case for such international space cooperation that is entwined with the elements of national pride and national security

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.

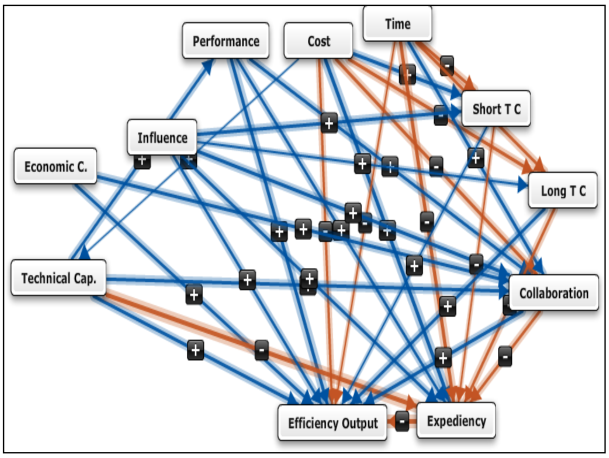

Figure 4: Cognition Model of Inter-relationship of parameters

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.

Measure Index	Range of variables	Values	Categories
Very Low	0-20	Less	B
Low	20-40	Good	B+
Moderate	40-60	Good	A
High	60-80	Very Good	A+
Very High	80-100	Excellent	A++

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++.

		Grade – partner nation			
		Less	Good	Very Good	Excellent
Grade – Host nation	Less	B	A	A	A
	Good	B+	A	A+	A+
	Very good	A	A+	A+	A++
	Excellent	A+	A+	A++	A++

Table 7 Gradation of Parameters

Fig 5a, 5b. Fuzzy Cognition Matrix

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_Variable* is *Less* AND
Time_Variable is *Less* AND
Performance_value is More **THEN**
Result Output is (Defuzzification) ***High.***

IF Cost_*Variable* is *More* AND
Time_Variable is *Less* AND
Performance_value is *LESS* **THEN**
Result Output is (Defuzzification) ***Medium.***

IF Cost_*Variable* is *More* AND
Time_Variable 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 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).

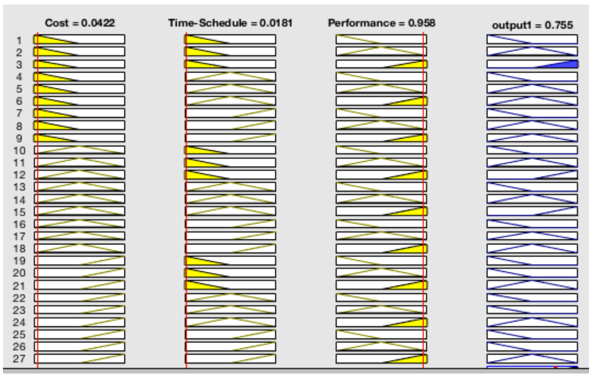

Figure 6. Cost-Time-Performance Fuzzy Model (red line moving towards right side indicates higher value)

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 Cooperation 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).

Fig. 7 Cooperation Success Index - Fuzzy Model

Resultant values indicate (Fig 6) higher chance of success if all parameters show positive trends. The India-Israel model showed an output value of (82.3%) success rate. This puts the grade of cooperation at A++ (Table 6 & 7).

If cooperation policy is not very active then cooperation success index is low. This implies that other than technical imperatives and cooperation history a policy orientation becomes the primary requirement for achieving higher results in India–Israel cooperation. Technical capabilities, regional domestic and global influence is appropriate for both India and Israel for space cooperation in strategic and security dimensions.

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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