Use of Independence, Non-Dependence and Interdepence as Strategic Elements in Space Partnership

*Marc Haese**

A vast number space missions and programmes today – and even more in the future – are based on bi- or multilateral cooperation partnerships. Interdependency is an integrate element in such cooperation and often strongly influences management and schedules. Interdependency is a risk factor for each partner, but at the same time possibly an instrument of political considerations. Whilst generally agencies would wish to pursue missions, like in exploration or Earth observation on an independent basis, it is often unavoidable to cooperate with partners, e.g. because of budgetary or technical reasons, when necessary technologies are not available at the required readiness level. Agencies are then confronted with the decision about how to implement a) critical technologies (maintaining independency), b) technologies which are locally available, but which for specific reasons are preferred to be acquired from partners (non-dependence), and c) technologies that are not available locally and therefore must be contributed by a partner. Another dimension of dependency is added by selecting a different funding concept for a programme, like public-private partnership (PPP) or commercialization. Against this background the paper tackles the question of a conscious approach to the selection of partner contributions, on programme, mission, system and technology level, aiming for a balance between priorities for independency and partnerships with mutual benefits. In order to focus the analysis, primarily, the viewpoint of space agencies has been taken. Examples are presented from the areas of exploration, science and Earth observation, complemented by a look at a PPP approach in navigation and commercialization in space transportation.

* DLR, German Aerospace Center, Germany, marc.haese@dlr.de. Note: The views and opinions expressed in this paper are the ones of the author himself and do not represent official DLR positions.

I Introduction

I.1 Background

In various areas of space, human and robotic activities today are being conducted by space agencies, institutions, academia and private enterprises in bi- or multilateral cooperation within a wide network of international partners. Budgets, which are tightly limited in most countries, and the delivery of value for stakeholders have become predominant boundary conditions that determine the volume and schedules within which missions and programmes can be pursued, particularly by space agencies. Space projects have to respond to the demands and needs of the major stakeholder groups: the general public, the science community, industry and the political community. Compared to other industry sectors space projects and programmes usually have a long time frame which makes them particularly vulnerable to the dynamics in regional and global economies as well as to changes in countries´ governments compositions. In order to respond to budgetary constraints and to build-up and maintain sustainable programmes space agencies are increasingly interested in exploiting synergies and complementing capabilities through cooperation with international partners. Thereby, questions of dependency have become an implicit aspect of space projects.

I.2 Types of Space Activities and Related Collaboration

There are various space sectors which are characterised by different features such a space craft types, objectives, funding and cooperation schemes, mainly (with major types):

- Earth observation satellites (governmental, military)
- Scientific and exploration missions (governmental, academia)
- Telecom satellites (commercial)
- Navigation satellite systems (governmental, public-private partnership)
- Launchers (governmental, commercial)
- Cargo and human rated transportation vehicles (governmental, commercial, private)
- Orbital structures (governmental, private)

In most of the space activities above collaboration on technical level is comparable. Systems, sub-systems, components or electronic parts may be acquired from partners e.g. through purchase, in exchange or even in kind contribution. Technologies, systems and even a space craft might be developed jointly. Payloads may be contributed in various types of missions and projects. Cooperation on technical level between international partners has become very common, and issues of dependency are part of it. An analysis particularly of dependencies on technical level in exploration programmes has been done in [1]. Another aspect of collaboration is related to the funding scheme of a space programme. Public-private partnerships (PPP) and commercialisation programmes are rather being implemented on national or regional, e.g. European

scale, whilst intergovernmental programmes often follow a no-exchange-of-funds principle.
Each collaboration creates a dependency to a certain degree at least for one partner and often for several partners. This dependency needs to be traded off against own priorities.
However, despite the fact that a high number of projects nowadays is conducted in collaboration, independence (or autonomy) is being pursued by most agencies particularly between technology and system level and is considered of strategic importance.
The chapters hereafter will investigate different types of collaboration and the resulting degrees of dependency. Due to the very different character of the space sectors listed above and the related high complexity of types of collaboration, some particular cases are being used to demonstrate the method of analysis. Furthermore, by means of some selected examples an approach of how to analyse risk mitigation will be presented.

II Types of Collaboration and Dependencies

As mentioned above there are different levels and types of collaboration, leading to different degrees of dependency. Major types of collaboration can be categorised as follows. (Note: For some of the examples – ExoMars, MPCV service module, Hayabusa-2 – a snapshot of the current situation is used for the analysis. The status of those projects is likely to change over time.)

II.1 Types of Collaboration

As introduced above, there are two major types of collaboration, A) on technical level and B) related to the funding scheme.

A) Collaboration on Technical Level

– Mission or Element Level –

(a) Joint Development of a Space Craft or Mission
Examples: (i) The CNES-DLR climate mission MERLIN, which measures the concentration of methane in the atmosphere. France is providing the satellite bus, whereby Germany is developing the payload. The mission is only possible with the contributions from both sides, therefore they are fully interdependent.
(ii) ExoMars in its current proposal (ESA: orbiter and rover, Roskosmos: launcher and landing system; both agencies adding scientific instruments) In this cooperation both partners would be fully interdependent. A successful mission is possible only with the timely delivery and functionality of all contributing elements: the launcher, the orbiter with scientific payloads from both partners, the Russian landing system transporting a European rover.

(b) Contribution of a system or sub-system/component to a partner´s element
Examples: (i) the currently discussed European Service Module for the US Orion Multi-Purpose Crew Vehicle (MPCV); (ii) contribution of a navigation sensor to a robotic spacecraft
In this type of collaboration the roles of partnering agencies, and thus the level of dependency for each, depends on the size of contribution.

(i) The contribution of an ESA service module for the NASA MPCV creates a true interdependency. The MPCV is not operable without the service module, and the service module would lose its purpose as barter element within the ISS cooperation, if the MPCV development would be terminated.
(ii) The contribution of a sensor or other sub-system/component by one partner likely results in a dependency situation for the leading partner, because the parts or sub-system cannot be acquired easily through an alternative provider. At least additional funding and efforts are required and time delays are likely.

(c) Contribution of a Scientific or Experimental Payload to a Mission
Example: Hayabusa-2, the Japanese asteroid sample return mission currently under preparation, with MASCOT, the German/French scientific payload.
JAXA, which is the owner of the Hayabusa-2 mission is non-dependent on DLR and CNES with respect to the scientific payload. The mission could also be conducted without MASCOT or with a replacement payload. From the viewpoint of DLR and CNES they are fully dependent on the Hayabusa-2 mission preparation and conduction.
Also imaginable is a payload which is designed to be placed on two alternative missions. This would make it non-dependent with respect to one specific mission.

– Technology Level –

(d) Joint Technology Development, Possibly not Related to a Specific Mission
Agencies combine their forces and competencies in order to develop a technology that is of high priority for both. There are many ways in collaborating in joint technology development, particularly, if it is not related to a concrete mission with binding legal and financial commitments, but driven by common priorities or joint interest. Generally, dependencies are limited due to the optional character of the cooperation.

–Architecture Level –

(e) Interoperation of Elements
Example: development of a robotic orbiter or lander spacecraft that uses a partner communication orbiter.
Two cases can be distinguished. Either, elements are planned to operate together and are therefore developed in parallel. In this case, both partners are highly interdependent, because no element can sensibly operate without the

other. In the other case one element is operating already – like a Mars communication orbiter – and a new element is developed and intended to utilise it during a later mission. Here, the new element is fully dependent on the services of the communication orbiter, which itself is independent in its functionality from the operations of the new spacecraft.

B) Types of Collaboration Related to Funding Schemes

(f) Public-Private Partnership
Public institutions (space agency and/or other) and the private sector (industry) share the costs and responsibilities for development, deployment and operation in a to-be-agreed proportion. The rational is to lower risks and costs on the institutional side, to develop industry competencies and competitiveness.
Example: the European satellite navigation system GALILEO, which initially was planned as a PPP between ESA/EU and an 8-member industry consortium. ESA/EU would have taken the development cost and 1/3 of deployment cost; industry would have paid 2/3 of deployment cost and full operating cost. Due to disagreement between partners the original PPP scheme was terminated in 2007, with the EU taking over most costs, ESA only funding part of the development cost. Therefore, the strong and complex interdependency between initial PPP partners has been changed to a simpler customer-contractor dependency.

(g) Commercialisation
Space agencies might decide to hand over project responsibility and risks from the institutional side to the private sector.
Example: the US Commercial Orbital Transportation Services (COTS), which intends to help US industry develop privately operated space transportation systems. NASA has the roles of lead investor, technical consultant and potential customer. By giving up the autonomy of a governmental owned transportation system NASA intends to lower costs in the long-term (by only purchasing services), lower its own responsibilities and risks. It has changed its priority from an independent access to LEO to the development of new space systems (Orion, SLS) for exploration missions beyond LEO.

(h) No-Exchange-of-Funds Scheme
Example: the intergovernmental agreement between the USA and European Member States on the European participation in the ISS, the International Space Station. The US, through NASA, is providing the ISS operation services whilst Europe, through ESA, contributes cargo transportation services with its Automated Transfer Vehicle, ATV. The European contribution has to match a certain financial volume, which has been agreed beforehand. Despite an initial interdependency between Europe and the US with respect to the use of the ISS (both, ISS operations and cargo services are required for the intended ISS usage of both partners), both partners maintain a high degree of non-dependency (NASA could acquire cargo services from another partner, ESA can opt for and negotiate with NASA about another type of contribution). Administration hurdles are kept on low level in this type of cooperation.

II.2 Classification of Dependencies

On the basis of the collaboration cases described above a classification of dependencies can be set up.

Independency, Autonomy

Independency, or autonomy, is the absence of any dependencies on a certain level, such as architecture, element, system, sub-system/component or technology level.

Non-Dependency

Being non-dependent means the capability to develop and provide e.g. a system or technology independently from external partners, but leaving the option open to acquire it from other sources if this is considered beneficial.

Inter-Dependency

Cooperation in which partners mutually depend on each other´s contribution.

Dependency

Single-sided dependency on other partner(s). The achievement of own goals has to rely on the functionality of other elements.
The following table provides an overview of the interrelations between the collaboration types and dependencies introduced above:
In most types of cooperation partners are inter-dependent or fully dependent. Only in rare cases a partner is independent from or non-dependent on another. This means that questions and issues arising from inter-dependency and dependency are a constant factor in space exploration cooperation. They need to be understood and agencies should be prepared to respond accordingly.

III Boundary Condition and Priorities

When considering cooperation with another partner the question of dependency is only one amongst several conditioning factors. From an agency's point of view there are external and internal factors that drive or at least influence the decision making process, and which directly or indirectly also influence the choice of collaboration.
The following External and Internal Factors are of generic nature and are applicable basically throughout the different space sectors. An exception is the telecommunication sector which is dominated by commercial activities and is ruled by market demands and competition.

III.1 External Factors

National Space Strategy and Priorities

A national strategy for space activities usually is the predominant driving factor for public space programmes and projects on a high level. Its priorities

Table 1 Collaboration types and degrees of dependency; (X) = to a certain degree

	Independence, Autonomy	Non-Dependency	Inter-Dependency	Dependency
Interoperation			X	(X)
Joint element or mission			X	
Contribution/ acquisition of system, sub-system, component		(X)	X	X
Contribution of payload		(X)		X
Technology development	(X)	X	(X)	
PPP			X	
Commercialisation		X		
No-exchange-of-funds scheme		X	(X)	

strongly depend on national goals and objectives, whereby today numerous governments demand in particular the delivery of benefits for society, innovation, development of strategic competencies and key technologies, and the advancement of industrial competitiveness.

Achieving autonomy on specific levels often is part of a national space strategy. In the case of the US Vision for Space Exploration in 2004 President George Bush set out a strategy that focussed on one single goal, the human lunar return by 2020, including the development of the transportation architecture (launcher and crew vehicle) in full autonomy. The Constellation Programme was initiated and affected NASA's structure and priorities significantly. The change in US presidency was followed by a termination of the Constellation Program and a new goal (human mission to an asteroid) with a modified combination of launcher (Space Launch System, SLS) and crew vehicle (MPCV) and – perhaps the biggest change in US space exploration priorities from the viewpoint of partners – the opening-up of the programme for partners to truly participate in it. A similar move has come this year from Russia, which still has maintained its full autonomy in human space flight, when Roscosmos offered to team up with NASA in a manned mission to Mars. It acknowledged that a project of such dimension cannot be achieved by a single nation but should be conducted in international cooperation.

In Europe the situation is more complex due to the co-existence of nations, the EU and ESA, many of which have their individual strategy. Generally it can be said that while Europe aims to maintain and develop its strong technological competence and industrial competitiveness in various areas. In short, medium and long-term space exploration it aims for close collaboration with international partners. Regarding the access to space the Ariane launcher has been an element of high strategic importance for Europe.

Smaller countries that do not have a fully vertically integrated space industry, e.g. like Canada, focus on the development of specific competencies. With a strong presence in space robotics, optical sensors and telecom/radar/microwave technologies Canada is looking to contribute, for example, to international exploration missions.

Another specific example is the UK where innovation, technology development, science and education from space activities are seen as direct contributors to UKSA´s Growth Strategy.

A special development towards international coordination and cooperation can be observed in international space exploration. In 2007 the International Space Exploration Coordination Group (ISECG) was established in response to "The Global Exploration Strategy: The Framework for Coordination" developed by fourteen space agencies [2]. In this document agencies recognize that different destinations and related mission scenarios require different challenges and risks to be addressed and that opportunities exist to exploit synergetic capabilities linked to different destinations. In September 2011 ISECG participating agencies have released the first version of the Global Exploration Roadmap (GER)[3] [4], which is consistent with existing policies and plans of participating agencies. It introduces a long-range strategy for future human exploration mission scenarios leading to a sustainable human exploration of Mars, and can serve as a common planning tool for participating agencies to enhance coordination and cooperation for exploration. Despite differences in details of individual space strategies agencies fully support and promote space exploration as a truly international endeavour that should be conducted in broad collaboration. The ISECG hereby is developing itself as a tool for coordination as well as a public demonstration of the will for joint space exploration.

Budgets

As already addressed above, the implementation of a space activities is closely linked to the budgets allocated to programmes. Space budgets have to compete with other governmental budgets, resulting in currently stable, but limited resources. Budget levels and programme timelines are determining factors in cooperation projects.

Commitments in Cooperation Frameworks

Participation in cooperation frameworks on higher level, such as the ISS, ESA or the EU, sometimes can set overruling priorities over national strategic priorities. Legal, financial or other commitments may lead to pre-determined cooperation partners.

III.2 Internal Factors

Key and Critical Technologies
Agencies usually have identified key technologies that shall be further developed in a sustainable manner on national level. Those developments often follow technology roadmaps that are regularly being aligned with the national space strategy. Technological excellence in industry and academia might have been developed, e.g., in past programmes and shall be maintained for future activities. In international exploration, an initial overview of key technology developments at agencies contributing to the ISECG Technology Assessment Team is provided in [2].
A specific segment of key technologies are critical technologies that have dual-use character. Their usage in projects, especially in cooperation, may require coordination with and clearance from other entities like the institution responsible for defence.

Industrial Policy
Based on the national industrial base and heritage agencies usually have identified key competencies at national industries that they aim to maintain and advance.

IV Adjusting Dependencies

The degree of dependency in cooperation is, to a wide extent, the result of external and internal factors that determine the decision making process. Therefore, dependency hardly can be managed isolated from the other factors; on the contrary, several factors including the degree of dependency interact with each other.
In many cases a certain level of dependency and related risks are accepted by partners, particularly in interdependent cooperation. On the other hand it could be desirable to diminish the level of dependency in some cases.

IV.1 Examples for Modifying Dependency
The following examples will demonstrate that for several types of cooperation there might be options to modify the degree of dependency in order to mitigate the risks within a project.
In order to perform a very preliminary evaluation of dependency vs. other influential factors a simple value scheme is used. Each factor will be assessed and valued for its degree of satisfaction:

- 0 = low or none,
- 1 = medium,
- 2 = strong.

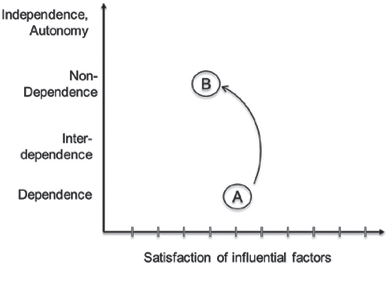
The sum will be related to the degree of dependency. In a second step modified project conditions will be assumed. Re-evaluating the sum of factor values and the effect on dependency, and comparing the result to the first case will make any changes visible and assessable.
In the following, three examples from the technical level and one related to funding schemes will be presented.

A) Contribution of a Scientific or Experimental Payload to a Partner´s Mission
Step 1:
Example: a payload contribution (like the German MASCOT) to an asteroid sample return mission (like the Japanese Hayabusa-2).

The payload usually is **fully dependent** on the leading mission.
Payload influential factors satisfaction: National strategy = 2 (fully in line); Budget = 2 (concept within budget frame); Commitments = N/A (national/bilateral project); Technology Development = 1 (new as well as proven technologies);
Industrial Policy = N/A (not very influential)
→ **sum=5**

Step 2:
Modification: the payload is being designed to also be able to fly on an alternative mission to another comparable asteroid in case that there are difficulties with the initial leading mission. This means an increase of costs through additional work and required higher flexibility in the schedule.
Now, the payload is **non-dependent** with respect to the initial leading mission.
Payload influential factors satisfaction:

National strategy = 2;
Budget = *1* (flexibility increases costs);
Commitments = N/A;
Technology Development = 1;
Industrial Policy = N/A
→ **sum=4**



The modification has resulted in a significant reduction of risk from dependency on the price of moderately increased costs.

B) Contribution of a System to an Element of a Partner Agency

Step 1:

Example: contribution of a major modular system to an element of a partner agency (e.g. the currently discussed European Service Module for the US MPCV)

The contribution of a major system to an element creates **interdependency** between both partners.

Influential factors satisfaction for system contribution:

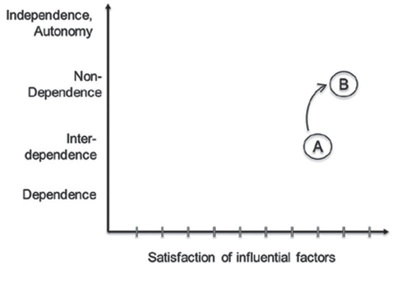
National strategy = 2;
Budget = 2;
Commitments = 2;
Technology Development = 1;
Industrial Policy = 1
→ **sum=8**

Step 2:

Modification: the modular system is being designed to also be used in other applications (e.g. a debris removal space craft). This would mean an increase of development costs, but at the same time the opportunity for additional technology development and more extensive engagement of industry.

Now, the module can be considered **non-dependent**. Influential factors satisfaction for system contribution:

National strategy = 2;
Budget = 1 (increased development costs); Commitments = 2;
Technology Dev. = 2 (add. developments);
Industrial Policy = 2 (more industry engagement)
→ **sum=9**



The modification has resulted in a reduction of risk from dependency as well as in a higher satisfaction of influential factors.

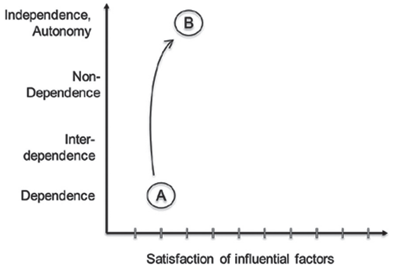
C) Acquisition of EEEparts for European Missions

Step 1:

Example: electronic, electrical and electromechanical parts (EEEparts) need to be acquired for the production of every spacecraft. In the case of European missions they often had to be purchased abroad, which could lead to schedule delays due to administrative procedures and legal issues (ITAR).

Due to the necessary acquisition of EEEparts abroad
Europe is in dependency to foreign suppliers.
Influential factors satisfaction for acquisition of EEEparts:
National strategy = 0;
Budget = 2;
Commitments = N/A;
Technology Development = 0;
Industrial Policy = 0
→ **sum=2**

Step 2:
Modification: the ESA European Components Initiative (ECI) aims at developing and producing all EEEparts in ESA member states. This means an increase of costs due to reproduction in little quantities and the need to maintain related production capabilities and workforce.
The ECI leads to European independency in the acquisition of EEEparts.
Influential factors satisfaction for acquisition of
EEEparts:
National strategy = 0;
Budget = *1* (increase of costs); Commitments = N/A;
Technology Development = *1* (more development in Europe);
Industrial Policy = *1* (increased engagement of European industry)
→ **sum=3**



The modification has resulted in a significant reduction of risk from dependency as well as in a slightly higher satisfaction of influential factors.

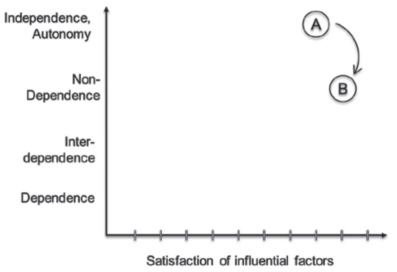
D) Commercialisation
Commercialisation as such is a modification in financing a space craft development.
Step 1:
Example: the US capacity of human and cargo transportation to LEO, particularly the ISS has been performed over many years with the Space Shuttle. The system was an institutional one, managed by NASA and implemented by industry.

From US and NASA viewpoint the Space Shuttle guaranteed **fully autonomous, independent** access to LEO.
Influential factors were satisfied like:

National strategy = 2;
Budget = 1;
Commitments = 0;
Technology Development = 2;
Industrial Policy = 2
→ **sum=7**

Step 2:
Modification: After the termination of the Shuttle programme, NASA decided to commercialise human and cargo transportation services, setting up the COTS programme. This means a decrease in the grade of independence, but with gains in cost and budgetary commitments and in other priorities of national interest (development of new systems for flights beyond LEO). Now, the collaboration can be considered **non-dependent**.
Influential factors are satisfied as follows:

National strategy = 2;
Budget = *2* (decreased costs in the long-term);
Commitments = 0;
Technology Dev. = 2;
Industrial Policy = 2
→ **sum=8**



The shift in national priorities has resulted in a loss of independency but still a gain in satisfaction of influential factors.

V Conclusion

– In most types of cooperation partners are either interdependent or one partner is fully dependent on the other. This means that questions and issues arising from interdependency and dependency are, and will be, a constant factor in space cooperation. They need to be understood and agencies should be prepared to respond accordingly.

- The degree of dependency in cooperation is only one conditioning element in the decision making process for projects and budgets. A set of external and agency internal factors have been identified that create priorities in the selection and preparation of missions. Within a project or programme the degree of dependency in cooperation is closely linked to those factors.
- Particularly in cases of interdependency and dependency in cooperation it can be desirable to consider modifications in the project planning in order to mitigate cooperation risks. In this paper a first approach for an evaluation scheme has been presented and applied. By means of selected examples it has been demonstrated that such risk mitigation is possible, sometimes on the price of lower satisfaction of other influential factors, sometimes even resulting in an increase of satisfaction. The pros and cons of modifications to programmes in order to achieve dependency risk mitigation need to be carefully assessed on a case by case basis and require a full understanding of agencies for their strategic goals, priorities and boundary conditions.

VI Acronyms

ATV	(European) Automated Transfer Vehicle
CNES	Centre National d'Etudes Spatiales (French Space Agency)
COTS	(US) Commercial Orbital Transportation Services
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Space Center)
ECI	European Components Initiative
EEEparts	Electronic, electrical and electro-mechanical parts
ESA	European Space Agency
EU	European Union
ISECG	International Space Exploration Coordination Group
ISS	International Space Station
ITAR	International Traffic in Arms Regulation
JAXA	Japanese Space Agency
MASCOT	Mobile Asteroid Surface Scout
MPCV (SM)	US Multi-Purpose Crew Vehicle (Service Module)
NASA	US National Aeronautics and Space Administration
PPP	Public-private partnership
SLS	US Space Launch System
UKSA	United Kingdom Space Agency

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CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA (European Space Agency), ISRO (India), JAXA (Japan), KARI (Republic of Korea), NASA (United States of America), NSAU (Ukraine), Roscosmos (Russia). 'Space agencies' refers to government organizations responsible for space activities.)
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