# Managing Interactions for Reliable Cooperation in a High Risk Technological Project (Human Space Autonomous Exploration System)

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**Abstract**
Designing a Human Space Autonomous system for the solar system exploration, needs a framework for understanding the processes that a complex project work entails, in particular to think about the interdependencies between individuals and the project and between human and technology This paper proposes to conceive the Human Exploration system like a cognitive entity able of both a wide range of anticipatory actions and perceptions in different unknowns to forecast environment. Our perspective is that the exploration system needs to exhibit self-learning and reliable aptitudes for self-organisation in unforeseen situations. Our paper proposes to conceive a process and a life oriented matrix able to aggregate different culture and languages in order to face problems for communication and cooperation at the early stage of the project.
**Keywords :** Human, space exploration, interaction, cooperation, autonomous

## 1 Human Space Autonomous System for the Solar System Exploration and Systemic Risks

Our objective is the design of an Human Space Autonomous system for the solar system exploration. The next step after the return to the moon, will be the exploration of Mars. For the Mars manned mission, the need to assure the autonomy[1] and safety of the entire exploration system is an immense task, both from a human and a technological standpoint, and especially during the design process stage. The exploration team will require an integrated technological system able to enhance its autonomy and safety at each step of the mission[2]. What is needed is an open, self-learning and reliable system[3] able to self-adapt in dangerous and unforeseen situations.

The foremost risk that we have identified with respect to the design process is that of conceiving the exploration system (which will support the mission) as a closed system,

[1] We made distinction between three types of autonomy, in link with the human system, the technical system and information system.

[2] There are four main steps with different environments and constraint: Low planetary orbits; Travel; Mars; Return (we can also divide the mission in 14 more detailed steps).

[3] The modes of proof for design an open, self-learning and reliable systems are on different register : 1. Human system → Representation, 2. Technical system → Models, 3. Information system → Calculation and Logic

and not as an open system[4]. The second risk is our concern that the centralised models of safety available today may well not be sufficient to respond to the security challenges of human long distance and duration exploration missions (Grès & Guyonnet, 2003).

This risk is enhanced by the multiple forms or configurations the exploration system might take during the travel. These configurations are unpredictable because of the complexity of the organization and the use of a large and various range of technology. Systemic risks may arise due to the limits of the centralized models of organization, limits which are indeed very perceptible on earth and in orbit (in the case of systemic accidents (Shawler, 2000). From this problematic emerge certain specific requirements for the design. It is necessary to :

- Give to the exploration system new capabilities, such as autonomy and cognition
- To make the conception process safe and reliable, especially concerning the socio-technical integration of the Global EXploration system (GEX - Coupling Human(s)-System(s)-Machine(s)).

We need a framework for understanding the processes that such a complex project work entails, in particular to think about the interdependencies between individuals and the project and between human and technology. The technical exploration system needs to be able to respond to complex systemic requirements. But before speaking about how to aggregate the many requirements and definitions in a specific way that guarantee and demonstrate an intrinsical safety. Let's see why speak of a Human Space Autonomous system ?

More precisely, the autonomous capacity of the exploration system must be augmented in accordance with a continuous learning process (Man(s)-System(s)-Environment(s)) to be renewed in function of time and space. This process makes possible the rapid adaptation of the system to numerous configurations, neither identified nor modelled in advance (Figure n°1).

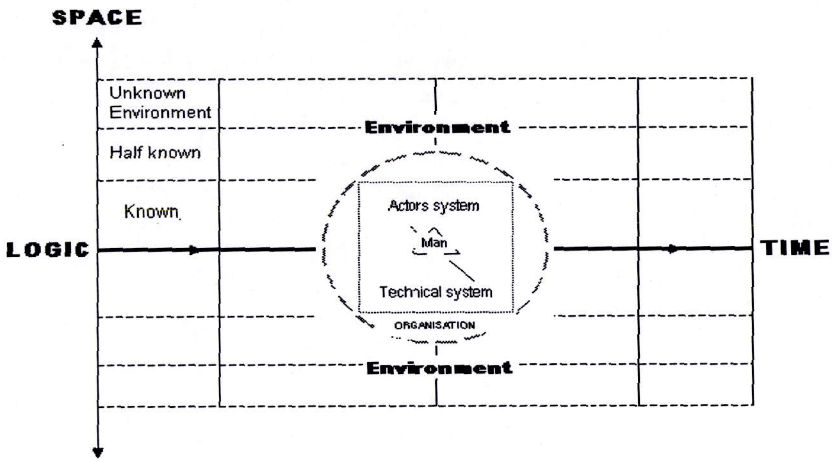


**Figure 1:** learning process (Man(s)-System(s)-Environment(s))

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[4] First definition : system that does exchange matter as well as energy with the surroundings

As we develop it in a previous article, the basic life principles and particularly the immune system should be able to guide us in our effort to improve the epistemological design of the safety system (Grès & Guyonnet, 2005). Due to the fact that the exploration system is deployed in a relatively un-known environment, we think that this is the key to the success of the Mars manned mission. Knowledge is partially uncertain and analogised because it is based essentially upon terrestrial data.

The exploration system must develop the "normal" properties attributed to any cognitive entity (Maturana & Varela, 1980). These are :

1. The ability to perceive and to act (sensory motor loop)
2. The link between perception and action is mediated by the merging properties of recurrence, which resemble a process network (operational closure in the sense of F. Varela.

Its action could be controlled by its perception, in such a way that the meaning constraints of the interaction field satisfy those of the environment.

# 2 Continuous Improvement of Learning Process for the Global EXploration System (GEX)

## 2.1. Autonomy, Consciousness and Interaction at the Heart of the GEX

Using The continuous improvement process of learning must be deployed as an integrated Human-technical system in co-evolution. Like a body mind organism (Hardy, 2001), it will then be able to run a constantly renewed conscious process of it own states in interaction with the environment. This design philosophy has 2 main objectives:

- To keep an adaptive process going between Man and his environment, by means of an interactive technical system.
- To avoid the risk of conceiving an open system in a closed one, with a Human centred methodology (model and matrix of interpersonal communication).

As a guide, we can use the image of an autonomous life system able to memorise dangerous or favourable events for survival.

Our hypothesis is that the capacity of autonomy is linked with the cognitive abilities of the system seen as a whole. It is an operational closure that merges from its interaction with the environment following a series of constraints derived from structural properties of the organisation (Varela, 1988). In our research, these properties are the result of the process which manages interactions between the partners of the project. Define and use the interaction unity principle will allow the emergence of reliable cooperation properties, we will develop this aspect in part 4.

In a previous article dedicated to the Human Space Exploration Mission "Decisional Information System for Safety" (Grès & Guyonnet, 2006), we proposed a DISS (Result of managing interaction for design) which makes the link between the actor system and the technical system. Its mission is to protect the exploration team and its mission in creating a favourable environment for decision making processes in unpredictable situations. The mission of the DISS is to enhance the team's decision making process when time allows, and to enable it to solve complex problems regarding the open system in critical situations and when the time span is short (Grès & Guyonnet, 2006).

We aim to design a safe exploration system in accordance with a set of entities in interactionnal synergy. This allow for the creation of an enhanced viability domain for the GEX. As we want to enhance the cognitive capacities of the GEX (Between information and action(s) possibilities, this lead us to fix (as principal objective) a life principle oriented design for a continuous learning embedded process capacity. It means that in the Human case of exploration, the need for understanding and manages an enormous amount of data lead to take precautions about the type of knowledge referential and the different logic that the GEX will use. We don't think that a prescriptive strategy with the choice of optimal solution is the only one to use, because in this case, a priori knowledge on the different environment of the Man-System entity will be imperfect, uncertain and imprecise. Even data that we are sure statically are human construction and we are limited by the possibilities of our scientific and natural observation disposal.

So we need to be conscious at the early stage of design that to be able to describe the GEX is an inverse function of its complexity (Bouchon-meunier, 1994).

The project of solar exploration needs an increasing degree of consciousness in relation to the demands of the environment. In order to avoid and resolve the explosive combinatory possibility risks and to increase the cognitive capacities we have founded our thinking on fecundity logic proper to basic life principles. Figure 1 shows those interactions at the heart of the life process and which are deployed between variety and unity in a co-dependent relation favourable to consciousness. But the process must be balanced continuously in order to maintain the system identity over the entire life cycle. This will be the rule of the structure of the interaction in part 4.

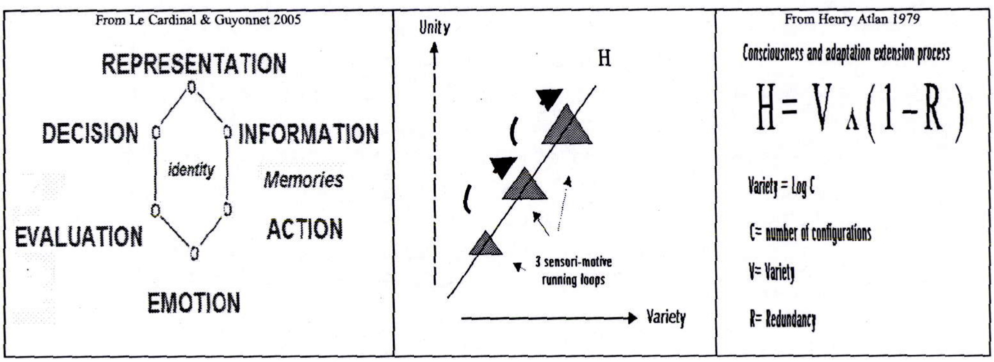


**Figure 2:** Unity and Variety

## 2.2. Three Requirements to Ameliorate Safety

In the reference design mission (Nasa, 1998) the long duration (near 1000 days), the scientific objectives and the dimensional constraints of the technical system (350 to 500 t. in low earth orbit) oblige us to understand and orchestrate the dynamical interactions between the human and human (cooperation) and between human and systems, first in the design stage, then in the operational context. At the early stage we must face problems for communication and cooperation for aggregating the many requirements and definitions. But if we speak first of how to increased safety, the system itself must satisfy at least three requirements :

1. To introduce some nuances (Fuzzy logic) between two categories of phenomena that the exploration mission will be confronted with (Sharp-Know, Fuzzy-Unknown).
2. Autopoïesis, plasticity and connectivity between agents are to be favorized as much as possible. The increase of communication between the agents of the system is required to respond to varied states that might occur in the system.
3. To simulate a large number of hypothesis from the inside of the exploration system. This is to answer to unforeseeable situations that imply discovery and learning beyond initial memories includes in the Decisional Information System (DIS) at its conception stage.

To better understand the problematic in relation with these 3 requirements, we present here a few characteristics of the design reference mission. The reference scenario describes an international mission for 2025. Figure 3 shows us the differences from the past Apollo mission. This data helps us to understand its technological aspects. But the cognitive aspect is also a key to the design of the system and to the creation of its adaptive skills. We will show a few examples to illustrate this point.

Earth-Moon

- Military crew of 3 members
- Distance 384 400 Km
- Time of travel : 3 days
- Mission : 12 days – 74 h 59 min on the moon (Apollo 17)

***Earth-Sun :*** 149 597 870,691 km (1 U.A)

Earth-Mars

- International crew of 4 to 7 members
- Distance from. 60 to 220 millions Kilometer
- Time of mission : 950 days

**Figure 3:** Earth-Moon / Earth Mars

# 3 Stakes of the Manned Mission and Methodological Path for Safe Design

## 3.1. Enhance the Exploration Team and Environmental Sensory Motive Loop

An automated system is founded on pre-identified functions, but in the case of a Human mission, we need an approach which favours the Human quality (and natural aptitudes) without drawing closed limits (or wrapped frame) with disciplines and job-skills boundaries.

For a Human mission, the design of the technical system must be determined by the exploration team's needs for support. An excessive automation without feed-back from the users creates problems that are already well known :

- User dependency
- Fall of contextual creativity
- Loss of vigilance

More than coupling Man & Machine, we want to enhance the exploration team and environmental sensory-motive loop. This can be made by a co-operation process controlled by the interpersonal communication model. 3 steps (co-operative design group) can be identified for designing a safe mission :

- Reference mission
- Accident reference
- History reference

The result of the Human-Human managed interaction will build the informational prosthesis, which create and increase meaning for the designers, for the support team and for the crew.

The way of organising functional sets of the exploration system has a very large influence on the design process. It needs both a complementation and alternation approach. Using models to stabilize the process of cooperation and fuzzy logic can help to conceive a more reliable mission architecture, which place man at the centre of the exploration disposal. At the management level, the need for communication and cooperation increase because of the complexity of the systems integration and indeed, increasing the gradations to close the subsets of functional modules allowed for the development of overall safety and distributes reliability over the entire exploration system.

## 3.2. Consider Interdisciplinary Especially During the Design Stage

The first aspect, which can help to improve exploration system security, is a dynamic reconfiguration at each stage of the mission life cycle. 14 stages show the transformation and the mission perimeters. The knowledge and security needed are not the same at each step. Figure n° 3 shows the chronology (Zubrin, 1996) and we presume that un-reliability will increase with each new configuration of the system. These un-reliability picks need to be confronted with non-classic methodology because of requirements due to the Human crew presence.

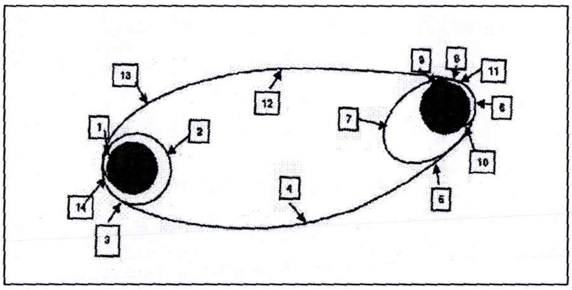


**Figure 4:** Chronology

In relation to the 3 requirements described in part 2.3.: 1.To built gradations: Known-Unknown, 2. Increase interactions, 3. Enhanced embedded simulations capacity. This represents a pathway to improve the security disposal for exploration.

**a)** The security of the crew obliges us to ask the central question : What can we afford to lose ?

This question relates to the design process and produces different answers with at least 2 domains of knowledge. The possible segmentation and articulations between the 2 domains are : Natural sciences, and Human sciences (with cognitive sciences). This interdisciplinary articulation is crucial for the intrinsic improvement of security of the GEX at its conception.

1. In the natural science frame, measurement of loss is : Energy, materials, and the objects to consider : Vehicle, men, mission

2. In the human and social sciences frame : incapacity to create meaning, and/or inability to extend the danger perception beyond limits of individual non dissociated entities. The principal statement at the beginning of this century is the emergence of fuzzy socio-biological-informational entity (Grès, 2003) with unpredictable behaviours. The September 11 attack and the SARS epidemic are examples that foreshadow this idea.

**b)** Improved security of the crew can not be reduced to an activation of the perception-decision-action loop in relation with the stage of the life cycle project. There must be improvement processes encapsulated at the heart of the system. It means, that it can be the result of a process of epigenetic learning (gained from previous space or terrestrial accident experiences) and it will be able to prevent risks in real time.

It will be :

- Intrinsic, because built and demonstrated during design. In this case the logic and the choice of models (out of time) allow the avoidance of mistakes analysed in complex current organisations. We underline again the major risk : To design an open system in a closed one.

- Historical, because the system must memorise the numerous environments that will be recorded. Each of them has its own particularities and hazards (with regard to the nominal prevented scenario).

**c)** To improve the security of the mission leads to the analysis of dangerous situations, especially the situations pointed out an adaptability insufficiency. Those situations can be linked with a priori scenarios of severe accidents (S3) or past experiences (S1/S2).

This is an example of a situation of non adaptation of the system in a different environment:

- S1 – Accident pattern of Challenger and Columbia
- S2 – Incident from Apollo
- S3 – Bad weather on Mars surface

**d)** Improved security leads us to show different strategies for solving potential accidents. Resources to activate for emergency can be various and the delays for problem solving cycles are on different scales (time, space, and ontology).

| From Earth to Mars and from Mars to Earth | Resources to activate in order to escape from a dangerous situation | Type of resources | Scale and unity |
|---|---|---|---|
| | - Material | - Material | n-Months – 3 to 6 months |
| | - Data or verbal information's | - Informational | n-minutes – t< 40 minutes |
| | - Toughs | - ... | V=C=0 |

**Figure 5:** Type of resources and scales

### 3.3. Safety, Culture, and Human Reliable Communication Process

These 4 aspects show us the necessity to create a team for solving potential problems. It is important to consider interdisciplinary especially during the design stage. The complex security problems concern each and every actor in the network of the exploration organisation. Intrinsic security is founded on the quality of the process of the entire life cycle of the project. A safety culture is a group responsibility that must be founded on a common reference fund (Lecardinal, 1989) between the designer, manufacturer and users. This safety culture can be increased to an international identity with a specific co-operation process and a method to stabilize it. This multicultural identity must be lead by respect of human being and the variety of life forms.

The building and demonstrating of the security of the exploration system will be based on a common reference fund shared between the designer, the manufacturer and the user. This common reference fund is partially interdisciplinary. Interdisciplinary could be defined as a novelty (paradigm and methodology) which emerges from the dynamic group interaction and will lay the basis for a safety culture. The key point to keep in mind is that the process of proof validation should be specific to each field of knowledge (Physics, mathematics, politics) and managed with an adequacy for a good integration process (Guyonnet, 2006):

- Dangers need a physical approach with models and practical tests
- Safety needs a mathematical approach with logical reasoning and calculation

- Risk needs an economic and political approach with human representation and qualitative reasoning, but also theories like fuzzy probability and possibility

## 4 How to Manage such a Complex and Innovative Project ?

We can propose a new path in link with two models that are connected together. Each one has a specific topic in link with human reliability (Lecardinal & Guyonnet, 2006):
a) Model of the unity of Interaction
b) Model of interpersonal communication
When the two models are connected this lead an approach for co-construction of a common representation and the issue of guidance for durable cooperation in a complex project. This is what we need for the international Manned Mars Mission in link with the requirements we explain in part one and two
a) First this approach is linked with a new way of seeing situations. For success in such a project, we need a third vision, a third person, a third logic and/or representation of the world. This space in between the two makes possible the coupling of each actor's gains, conditions that allow to increase trust and cooperation.

The model which is the unity of interaction defines as an elementary situation for two actors free and conscious (Guyonnet & Lecardinal, 1984). They can not have free access to their choice because they depend one each other. Because of their mission, they can interact and determine the common event.

| Astronauts<br>Designers | Choice 0 | *Choice 1* |
|---|---|---|
| **Choice 0** | *e1* | e2 |
| ***Choice 1*** | e3 | e4 |

**Figure 6:** Unity of interaction

The conception of an embedded and continuous improvement process to increase security must advance in relation with a good articulation of the necessary skills and knowledge. The integrity of the overall exploration system is founded on a reliable interaction and good communication within the system. That is to say that the design process must be managed by a reliable Human communication model (and process) from Man to Man to Machine-machine interrelation.

One example is the prisoner dilemma which shows a universal paradox. Two people A (Astronauts) and B (Designers) must take a decision between two options. There are four possible results and each result is associated to a gain or a miss for each player. If the person A decide to make the choice O, which we call the pacific option, and the person B chooses the same option, then A and B make success to gather for example one Euro. If A chooses the (0) option (the pacific one) and if B choose the second option, designed by 1 and which is the aggressive option, then A looses two euros and B gains 2 euros. Symmetrically if A (aggressive) choose 1 and if B (pacific) choose 0, then A gains 2 euros and B looses 2 euros. Then if A and B take both the aggressive option, they loose both one euro.

The cooperative issue (0,0) generates a gain of one (1) for the actor A and B and the aggressive issue (1,1) generates a loss equal to -1. The temptation of treason in order to take the maximum gain (+2) is almost there, and the fear from being betrayed is there with the over loss.

Then we can suppose that the two actors play not only one game but a succession of games. The cooperation situation (0,0) is unstable: because if there is a behavioural change from both two actors, this will be a gain for the one who is aggressive, on the contrary, the conflict issue (1,1) is stable. Each unilateral behavioural change will provoke a bad situation for its author. This is an equilibrium point. Alas, the gains from the conflictual issue (1,1) are less for the two actors, than these coming from those of the cooperative issues (0,0). We are here in front of a paradox because it seems that the two actors prefer to loose than to cooperate.

So the issues are :

- (0,0) is a state of cooperation which will be favourable for the two actors. If they could maintain this unstable state, but this state is very unstable because of the permanent temptation of treason for the two players. (1,1) is a conflict de favourable state that we wish to avoid, but unfortunately stable, because when this state is there, only one simultaneous change of strategy could make a possible escape from the situation.
- The issue (0,1) and (1,0) are from different nature than the (0,0) and (1,1), these are transitions between diagonals cases of the matrix on figure 1 and they are highly unstable because they correspond to the biggest gap of gain between A and B. They correspond to the victory of one and to the defeat of the other. Because the looser can not agree with this situation for a succession of game, the game can not be played a lot of time…Except if the looser accept to loose is free liberty of choice. This in comparison with the cooperative issue, represent temptation of a bigger gain, of a victory on the other.
- This issue (0,1) and (1,0) are resulting from different choices and so from opposite, ante-symmetric behaviour of the two actors.

The game theory is a quantitative variation of such a structure but we will not develop the explanation (Neumann & Morgenstern, 1944),. The result of research shows that if we want to develop a trust strategy, we can make a virtual coupling (by free will) of their gains. This coupling which is perceived and decided by the actors is an expression of the trust level that one actor allow to the other. This kind of reasoning can stabilize the cooperation process with some conditions that are in link with what the actors accept to realize in common. The intensity of the feeling dilemma depend on the coupling / un-coupling that the actors accept to do "in their mind".

Such a structure : Unity of interaction allows creating a language representation in which the actors can express three types of feeling: Attraction, Fear, Temptation (A, F, T). In themselves and in their relations with other people.

The AFT, is a new language representation which is very useful for the actors because they can tell the possible feeling in a dilemma situation. With a simplistic calculation, we can show that the positive coupling of the gains can permit to reduce fear and temptation and to increase Attraction. This can create the stabilization of the cooperation process. In a few words, we can make a link between actor's motivations in an interaction situation and the feeling of Fear, Attraction and temptation.

A human person needs to make meaning in order to act and its actions are founded on desires, ethic and values and these are a very essential part for understanding Human affairs (logical strategies).

So, what is acting in a dialogue ? How can we facilitate and orchestrate communication between different points of view ? That is what shows the model of interpersonal communication.

b) "Information is a difference that makes a difference" said Gregory Bateson (Bateson, 1979), and communication is a complex and interactive process. When two people communicate, their cognitive systems generate differences and they will progressively understand their identity. The way they will manage differences in a cooperative or in a competitive manner will build a good or a bad climax for relation and give (or not) some possibilities of a good management of their interactions. The level of trust fixes the possibilities of stabilization of the cooperation process.

In the model, we can distinguish four communication processes. This allows to understand the complexity of a such interaction between humans :

1. Information transfer (Criterion of quality: Though)
2. Managing common action (Criterion of quality: Cooperation)
3. Creation of relation and confidence (Criterion: Trust)
4. Discovering identity (Criterion: Estime)

The first two : **Information** transfer and managing **action(s)** are visible process that are already describe in a lot of communication theories, but the others are not visible and they are the key for understanding the communication actions and their impact on the cooperation.

## 5 Conclusion

These allow building a shared evidence fund between the actors, to evaluate the reliability of their relations and to make them discover their specific identity.

As we see in the first part, if we want to increase cognitive abilities between information and action we need the other dimension some hidden dialogic can generate specific dilemma in one of the four communication process and in one of the seven step of the model (1. Presence, 2. definition of the project, 3. qualification of the project, 4. realization of the project, 5. evaluation of the results, 6. sharing of issues, 7. Absence).

This permits solving some difficulties encountered in the management of a complex project. A such approach give birth to a method call PAT-MIRROIR. This approach is very near Edgar Morin thought because of the following reasons (Morin, 1977):

- It take care about dialogics
- It take in account recursivity
- It include an hologramatic principle

Those three conditions seem to appear as factors that create some innovative solutions which are adapted to the complexity of the exploration system. The key point is that preconisations are made by the actors, and they are directly adapted to practical difficulties encountered. Then a durable cooperation can be established with dynamical meaning founded of a renewed common representation of the project.

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