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Risk Management in Space Activities: Reproduction of Validated Routines

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Abstract
This paper puts forward a new way to manage risk in case of unaffordable disasters and failures. Using the example of space activities and High Reliability Organisation frameworks, we will show that the reproduction of validated routines may be a major way for organisations to exhibit high levels reliability.

In order to face high levels of risk, large space organisations have developed a rigorous knowledge codification and tend to reproduce routines within the phase of project planning and in the context of firm relationships. Reproduction of validated routines is a relevant tool to mitigate risk and to manufacture reliable technical systems.

Key words: Risk management; Reliability; Failures; High Reliability Organisations; Space activities

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INTRODUCTION

With a remarkable record of 113 successful missions and only 3 launch failures, Ariane 4 is the most reliable commercial space rocket that has ever been manufactured. One of these 3 launch failures results from a trivial error which would have no major consequences, if space activities were not so risky. The crash investigation concluded that the failure was caused by an unscheduled intervention on the boosters of the first stage. More precisely, someone forgot a piece of fabric on the feeder of one of the four Viking boosters of the first stage. This led at first to an unbalanced thrust and then to the crash of Ariane 4 (Ritchie & Lallour, 1998).

This unfortunate failure underlines that technical failures may result from errors in the task coordination made by organisations. As technical systems are never exclusively manufactured and operated by other technical systems, the organisations might obviously be responsible for technical failures.

This type of failures is called by Vaughan (1990) the "organisational-technical system failures" and this paper explores this issue through the example of space activities. Several scholars such as Turner (1976), Perrow (1984), Roberts (1990), LaPorte and Consolini (1991) share the standpoint that the source of technical failures may be found in organisational area.

In order to analyse this issue, scholars assume that organisations which are operating risky technical systems face more frequently those "organisational-technical system failures". These organisations are a specific group called the "High Reliability Organisations" (HROs) and for instance they can operate naval aircraft carriers (Weick & Roberts, 1993), air traffic control systems (Weick, 1990) and nuclear power generation plants (Bourrier, 1996).

The risky nature of HROs activities is the reason why they have developed organisational solutions in order to exhibit high levels of reliability. HROs are broadly engaged in risk management in order to prevent unaffordable failures. The need to exhibit high levels of reliability is strongly related to an organisational pattern focused on the avoidance of failures.

Large space organisations like space agencies and manufacturers are also very engaged in risk management, when they manufacture and operate space rockets, satellites and space probes. Within space activities, failures are unaffordable, because space technical systems come into operation either far away from Earth, or somewhere in space or on other planets. In consequence, space HROs cannot fix defective technical systems when those are in operation and reliability commitments are focussing on manufacturing activities.

This article analyses how space HROs mitigate risk in order to prevent unaffordable failures. We claim that the impossibility to fix space technical systems when those are in operation induces that risk management is based on the reproduction of routines validated in previous programs.

In order to demonstrate our argument, we will exploit documents made by scholars, journalists and space engineers on space activities and more particularly on manufacturing activities. We will also exploit some parts of a study conducted in 2005 within a large European space manufacturer and one of its suppliers[1].

The article is structured as follows. Sections 2, 3 and 4 present the main features of space HROs through the issue of risk. Section 5 explains why the reproduction of routines is a relevant strategy to maintain high level of reliability. Sections 6 and 7 provide evidences of this argument in space HROs. Section 8 and 9 are respectively a discussion and a conclusion.

1. LARGE SPACE ORGANISATIONS ARE HROS

The example of the *Venera* program which was accomplished by the Russians may be used to provide a first clear view of the nature of the activities conducted by large organisations in the space industry.

During the 1960s and the 1970s, Russians decided to explore the Venus planet thanks to several space probes which were named *Venera* (Brunier, 2006pp. 173-175). Due to its proximity with the Sun, this planet was regarded as a tropical paradise before space exploration started. It is only after 6 unsuccessful attempts that the Russians found out that this assumption was completely false. Thanks to *Venera 7*, the scientific community realised that Venus is in fact a very hostile planet with an atmospheric pressure which is 90 times higher than on Earth, with a temperature higher than 490°C and with acid sulphuric rains which rapidly erode any type of equipment. This discovery did not discourage the Russians, because they sent 9 more space probes towards Venus in order to analyse more accurately the nature of this planet. The *Venera 15* was the most reliable version during this space program and it has been operational only 2 hours in the Venus environment.

If we add now that the cost of a space program is today between 4 billion dollars and 7 millions dollars, and above all, the cost of a failure often reaches 600 million dollars (Ritchie et al., 1998, pp. 836), we may say that large space organisations are conducting activities at the end of the spectrum across risky technical systems.

This example underlines the fact that large space organisations such as space agencies and space manufactures are member of the specific social group of organisations called High Reliability Organisations (HROs). We share this standpoint with some scholars who have treated the topic of HROs like Perrow (1984), Vaughan (1990), Bigley & Roberts (2001), Roberts & Bea (2001).

According to Vaughan (1990), large space organisations, like NASA[2], are dealing with risky technical systems when operating space shuttles. Bigley and Roberts (2001, p. 1293) add that organisations which are operating space shuttles are HROs and Roberts and Bea (2001, p. 71) enlarge the argument by saying that organisations that manufacture and operate technical systems such as the Mars Climate Orbiter and the Mars Polar Lander are HROs. Finally, we may say that organisations that manufacture and operate space shuttles, space rockets, space probes and satellites are HROs.

The risky nature of the activities of large space organisations brings us to consider them as HROs. However, space HROs show one feature which induces that they might be seen as specific HROs.

2. MAIN FEATURES OF SPACE HROS

2.1 The Specificity of Space HROs

According to LaPorte (1996, p. 60), the two main features of classic HROs are the following: on the one hand they are able to manage risky technical systems, and on the other hand they have the capacity to meet very high peak demand and production in periods of emergency. Space HROs manage risky technical systems; however they are less impacted by the issue of high peak demand and production in periods of emergency.

This situation results from the impossibility of space HROs to fix most of the breakdowns which occur in operation. It is very difficult to scrutinise the nature of a breakdown and to fix it when the technical systems are unreachable, because they are far away from the Earth. As Roberts and Bea (2001, p. 71) have noticed for the losses of both, the Mars Climate Orbiter and the Mars Polar Lander, the glitches were simple but it had been im-

[1]These organisations prefer to be unamed.
[2]National Aeronautics and Space Administration.

possible to fix the problem. Space HROs cannot interact directly with the damaged space probes, or satellites. They cannot send astronauts to fix the breakdown, because it would be more expensive than the entire space program.

Aside from the case of Hubble, where the space telescope was designed to be regularly serviced by astronauts, large space organisations do not send astronauts to fix breakdowns (Brunier, 2006, p. 127). Space HROs are only able to attempt minor actions like updating software or trying some uncertain undertakings that may reduce the service life of the damaged technical systems. For example, when solar panels of a satellite do not open, engineers may decide to *'shack'* the satellite by activating the propulsion systems. This choice might eventually work, however it consumes a significant volume of the fuel needed to maintain the orbital position of the satellite during its service life (Ritchie & Lallour, 1998).

As, in space activities, it is very difficult to fix breakdowns during operations, the issue of high peak demand and production in periods of emergency is less relevant than in classic examples of HROs such as naval aircraft carriers (Weick & Roberts, 1993), nuclear power generation plants (Bourrier, 1996), air traffic control systems (Weick, 1990). This is why we will not handle the issue of emergency crisis management in space activities in this article. On the contrary, this paper focuses on *ex-ante* crisis management.

The difficulty to fix space technical systems in operation underlines the relevance of the *ex-ante* crisis management issue. One of the main ambitions of space HROs is to mitigate the risk of failure before launching their products in space environment. E*x-ante* risk mitigation is essential in order to prevent potential insolvable breakdowns in operation. In this paper, we assume this *ex-ante* risk mitigation is strongly related to the nature of the manufacturing activities.

2.2 Space Activities are Risky

A general rule in insurance theory says that the extent of disasters is a negative function of their occurrence. This applies to most of the activities; however it is not the case for the activities conducted by HROs because these organisations "can commit catastrophic errors in a number of ways" (Roberts, 1990, p. 162). More precisely, in space activities the extent of disasters often reaches 600 million dollars and simultaneously their occurrence is 1/8 (Ritchie & Lallour, 1998, p. 836).

Many scholars on HRO literature underlined that HROs are dealing with risky (or hazardous) technical systems (LaPorte, 1996; Rochlin, 1996; Demchak, 1996, Mannarelli, Roberts et al., 1996). We consider that among the HROs, it is the space HROs which are manufacturing some of the riskiest technical systems. The idea of LaPorte that many HROs should not exist because they face important risks suits for space HROs because to manufacture a space probe which will come to operation in new worlds is one of the most ambitious undertakings of human being.

In order to specify the nature of the risk faced by space HROs, we can use the general definition of risk provided by Kahneman and Tversky (1979). Risk is defined on the one hand by an amount of losses and on the other hand by an assessment of uncertainty. Both of these parameters are significant in space activities.

In HRO literature, the amount of losses is called the "*cost of error*" and Roberts (1990, p. 174) argues that this cost of error reaches very high levels. In space activities, it is mainly linked to the cost of the damaged technical system. We have already noticed that it is very difficult to fix breakdowns in operation. In other words, the cost of error tends to be high, because it is close to the cost of the entire space program which might eventually be cancelled. Another reason for the cost of failure is so high is the small batches produced by space HROs. In 2001, only 51 space rockets have been launched in the world. In the majority of cases, each satellite or space probe is unique and even the most important manufacturers do not deliver more than around ten units per year (Brunier, 1996, p. 163). Consequently, a single failure would be serious for organisation survival. Moreover, the cost of error is also very high, because it includes other elements like the cost of collateral effects of a failure. One single failure may compromise funding from private or public sources and also threaten competitive or military advantages (Vaughan, 1990).

As all HROs, space HROs have to manage risk in their activities, because they face high levels of uncertainty. To send a space probe towards worlds where no one has ventured before obviously induces significant levels of uncertainty. We may provide some statistic information in order to specify this point. In space activities, 7% of failures have an unknown explanation (Ritchie & Lallour, 1998). In space probes manufacturing, we count 97 failures and 16 partial successes among the 221 space probes launched since the beginning of space exploration[3]. In other words, the rate of failure is very important and reaches 43,8%. The reliability of space rockets is higher, however their rate only reaches 98.5% for the most reliable, namely the Ariane 4 (Brunier, 2006, p. 208). These figures have to be compared with the rate of reliability of airliners which is 99.99%.

[3]The figure 221 refers to the number of space probes which have achieved their mission in 2008.

3. RISK MITIGATION IN SPACE THANKS TO A CULTURE OF RELIABILITY

The important risk faced by space HROs induce that they are not failure tolerant organisations contrary to mass production organisations. In consequence, and as already noticed for classic HROs, space HROs cannot afford trial and error strategies either (Roberts, 1990, p. 160; LaPorte & Consolini, 1991; Demchak, 1996, p. 97).

In order to cope with this hostile context, HROs carry out adaptive behaviours that aim at increasing reliability (LaPorte & Consolini, 1991). More precisely, scholars noticed that there is a necessary culture of reliability in risky activities (Roberts, 1990, p. 173; Roberts, Stout & Halpern, 1994). Due to the difficulty to fix space technical systems in operation, space HROs developed this culture of reliability in their manufacturing activities.

This culture may be noticed in a general way by the capacity of space firms to be pioneers in the implementation of quality standards. During the 1960s, the space industry invented quality control methods in order to face the risk surrounding space exploration (Bach, Cohendet and Schenk, 2002). A study conducted in France by Ravix (2000), indicates that 96.9% of the aerospace firms had already adopted quality assurance in 1994. In comparison, only 49.3% of the automobile firms and 26.8% of the firms belonging to industrial sector had adopted quality assurance in 1994.

The culture of reliability may also be stressed by the importance of technical competencies and by the organisational redundancy existing in manufacturing activities. Technical competencies usually shape authority relations and decision processes in HROs and then it is obvious to notice that 60% of the staff in European aerospace industry is composed by engineers and highly qualified technicians (Michot, 2004).

The redundancy is observed though a noteworthy specificity of the assembly phase. In order to make sure that all work is well done, there will be one person who assemblies the system and another person who simultaneously writes down each work step. This organisation of the assembly phase tends to contribute to organisational redundancy, because these two persons switch after each task.

4. REPRODUCTION OF ROUTINES IS A STRATEGY TO MAINTAIN HIGH LEVELS OF RELIABILITY

We consider that another important feature of the culture of reliability of space HROs is the reproduction of the routines validated in successful programs.

By routines, we mean the place where organisations store their operational knowledge. They can be regarded as a highly structured set of ‘habitual reactions’ linking organisation members to one another and to the environment. They are all regular and predictable behavioural patterns of organisations. In consequence, organisations may be expected to behave in the future according to the routines they have employed in the past. One other major feature of routines is that they can persist only if they are reproduced continually. This argument explains why evolutionary scholars assume that organisations remember by doing (Nelson & Winter, 1982).

This major argument of the evolutionary theory introduces an important difference between reaching and maintaining high levels of reliability. We use this difference to understand why reproduction is needed to ensure reliability.

As Hannan and Freeman (1984) noted, the organisational behaviour which is aimed at reaching high levels of reliability is different from the behaviour that serves to maintain them. In order to reach high levels of reliability, organisations have to switch from an unsatisfying situation with low levels of reliability to a satisfying situation, where the levels of reliability are high. This requires that organisations search for new routines or imitate the better routines existing within other organisations. This change of routines leads to the implementation of some managerial tools used to increase reliability such as quality assurance, knowledge codification, phase project planning design review and PERT methods.

Reaching high levels of reliability is the first step of *ex-ante risk* mitigation; the second step is to maintain these high levels as long as possible. This second step requires a completely different strategy from the organisations. Instead of changing existing routines, organisations have to maintain all routines which have led to the increased reliability. As noticed by Hannan and Freeman (1984, p. 154) *"reliable performance requires that an organisation continually reproduces its structure"*.

When organisations do not conduct risky activities, like in mass production industries, the reproduction of validated routines might be a secondary target because a failure induced by a variation of the routines does not induce a disaster. Space HROs obviously face a different situation because a bad reproduction of validated routines has major consequences. In this case managers are concerned themselves with trying to prevent variation and the routines progressively take on the quality of norms.

Of course, it is not the organisations' objective to reproduce strictly the validated routines. Exploitation and refinement of those existing routines are of first importance. However, our standpoint is the following: the more organisations face an important risk, the stricter will be the aim to reproduce validated routines.

All these arguments show that the issue of reproduction of validated routines is very relevant for *ex-ante* risk mitigation in HROs. In consequence, it is obvious that studies on HROs often stress the need to prevent changes.

For instance, LaPorte (1994, p. 61) underlines that any change is more likely to degrade than to improve the reliability exhibited by HROs. Roberts (1990, p. 169) and Bourrier (1996, p. 109) also share this point of view, when they respectively notice that the captain of the Theodore Roosevelt aircraft carrier insisted on never breaking a rule, unless carrying out this rule would mean a threat for safety; and that nuclear power plant management believes that last minutes ideas, even good ones, can endanger the whole planning exercise. A study of Bigley and Roberts (2001) on a fire department puts forward a similar idea by observing the importance for organisations to maintain the mental models in order to be more efficient in emergency situations.

5. REPRODUCTION OF ROUTINES AND KNOWLEDGE CODIFICATION IN SPACE MANUFACTURING

In case of unaffordable failure, a major objective of *ex-ante risk* mitigation is to maintain the high levels of reliability which have been previously achieved by the organisation. The most obvious way to maintain them is to reproduce the validated routines that have led to reach these very high levels of reliability. Indeed, "a skill that is only exercised briefly every year or two cannot be expressed with the smoothness and the reliability of one consistently exercised five days a week. […] Coordination is preserved, and organisational memory refreshed, by exercise- just as, and partly because, individuals skills are maintained by being exercised" (Nelson & Winter, 1982, p. 107).

As already noticed, the investigation on the one of the 3 launch failures of Ariane 4 had shown that the crash was caused by an unscheduled intervention on the Viking boosters of the first stage (Ritchie & Lallour, 1998). This example of failure underlines the fact that even a minor variation within manufacturing processes may be catastrophic. In consequence, space HROs, like classic HROs, adopt very detailed procedures in order to prevent the risk associated with any unordinary intervention (Bourrier, 1996, p. 108).

More precisely and according to the statement of Bach et al. (2002, p. 16), space manufacturing is based on a rigorous knowledge codification with the aim to convert the relevant tacit knowledge required to ensure high levels of reliability in explicit knowledge (Nonaka & Takeuchi, 1995)

Our study realised in a major European satellite manufacturer confirms this point. The space engineers in charge of assembly and test phases try to maintain the same manufacturing processes for all type of satellites produced; namely for military satellites, scientific research satellites, and telecommunication satellites. By using very similar manufacturing processes, space engineers hope to prevent dangerous variations and potential failures.

In the same way, we previously noticed that during the assembly phase, in order to make sure that all work is well done, there is one person who assemblies the system and another person who simultaneously writes down each work step. This type of organisation is used to assemble standard technical systems. When critical technical systems for the mission are assembled there are more persons involved in order to control more accurately if the work is done according the validated manufacturing processes. For instance, the assembly phase is particularly rigorous for telecommunication satellites because they will be used in commercial activities like TV broadcasting. In this case, manufacturer has to provide clear evidence that he respected the validated manufacturing processes in order not to be found guilty of possible failure. The documents written during assembly phase are called *Acceptance Data Package* and they are very important to ensure a rigorous compliance between validated manufacturing processes and performed manufacturing processes.

The second main document used in satellite manufacturing is the *specifications file.* This document is written at the beginning of satellite project (namely during the design phases), and it precisely describes the nature of each technical system of the satellite and the way to assembly them. The specifications file of a new project has to exhibit a compliance with specifications files of previous projects.

As noticed d'Armagnac (2004, p. 224), space manufacturing is largely based on detailed documents that describe the nature and the schedule of tasks. These documents are a burden for organisations, yet, as they are based on similar documents validated in previous programs, they help space HROs to maintain high levels reliability in their products.

D'Armagnac (2004) also noticed that large space organisations show highly formalized manufacturing processes and this feature is very specific for space industry unlike as for other industries. Our study conducted in a firm which is working both for space manufactures and shipbuilders underline this point. The team manager explains that, when working for space customers, tasks which are linked to knowledge management, e.g. the precise recording of each working step may represent 50% of the entire working time - while it only represents 20% of the working time when the team is working for shipbuilders.

6. ORGANISATIONAL INERTIA: A PROXY OF ROUTINES' REPRODUCTION

The tendency of space HROs to reproduce validated routines in order to maintain their high levels of reliability may also be underlined through situations of organisational inertia existing within space manufacturing (Dos Santos Paulino, 2006). We assume that organisational inertia may be a proxy of reproduction using *Assumption 3* of Hannan and Freeman (1984, p. 154): "High levels of reproducibility of structure generate strong inertial pressures". In other words, we may say that there is a link between the organisational inertia exhibited by space HROs and their tendency to avoid changing routines which have been validated in successful previous programs.

6.1 Organisational Inertia in Space Organisations

During the 1960s and 1970s, in a context of space competition between USSR and USA, NASA searched for new ways to provide safety technical systems to its astronauts. At that time, space HROs were pioneers concerning several manufacturing solutions implemented to ensure high levels of reliability. Within their internal and external manufacturing processes, large space organisations were among the first to use quality assurance, Phase Project Planning (PPP), design review, PERT methods[4] and sophisticated firm relationships in big consortiums (Bach, Cohendet & Schenk, 2002). These new manufacturing solutions strongly helped large space organisations to increase on the one hand the level of reliability of their technical systems, and on the other hand to become HROs.

Due to the success of these manufacturing solutions on reliability, organisations from mass production industries decided to adopt them. This adoption is known as the mechanism of *spillover* (Mowery & Rosenberg, 1989).

When mass production organisations adopted those manufacturing solutions they also adapt them to their manufacturing constrains. This adaptation led to several improvements in PPP and in firm relationships. Yet, we observe that space HROs preferred to maintain unchanged their PPP and firm relationships instead of imitating mass production organisations.

6.2 Reproduction in Project Phase Planning

In space activities, Phase Project Planing (PPP) was initially designed to allow organisations to conduct huge projects like Apollo program. More precisely, PPP was based on the idea that large space organisations are designed to cope with each aspects of the project. In other words, it is difficult to separate the organisation from its project. PPP was initially based on sequential phases, where the main phases are: *mission analysis, feasibility study, preliminary design, detailed design, production, assembly and test*.

Organisations of the mass production industry decided to overlap their specific phases of manufacturing such as market analysis, design, production and marketing in order to reduce time to market. Today most of the mass production organisations have given up PPP which is based on sequential phases and have instead adopted a concurrent management where many phases are simultaneous. This change has helped to provide more frequently new products to consumers and then to increase profits of mass production firms.

By contrast, the PPP of space HROs is rarely based on simultaneous phases (Alcouffe, 2001). There was for example no real overlapping in the Spot program where the aim was to provide high-resolution images by launching 5 earth observation satellites between 1986 and 2002. We could only notice a minor overlapping between the preliminary design phase and the detailed design phase, where space HROs began with the procurement before having finished the validation of the general technical solutions (Potteck, 1999). The other phases stay sequential which induces a real difficulty to reduce time to market in an industry where organisations need several years to manufacture one single satellite.

We consider that space HROs willingly reproduce a PPP which is close to the PPP invented at beginning of space exploration, because it is a relevant choice to face high levels of risk and to prevent unaffordable failures. Space HROs avoid deep changes in PPP and prefer refinements.

6.3 Reproduction in Firm Relationships

We notice a similar situation, concerning firm relationships.

In order to conduct huge projects in space exploration, e.g. the Apollo program, large space organisations have invented sophisticated firm relationships, where firms are rather standing in a partner relationship, than in a customer supplier relationship. This new way to regard large firm relationships was been implemented during 1960s and 1970s, and it was very useful to increase reliability in space activities. Indeed, these firms relationships permits to conduct huge projects where no one can have all of the required competencies, and to share the cost of failure and the cost of R&D with partners.

The success of large firm relationships has stimulated mass production organisations to adopt the same type of firm relationships. This adoption led to a generalization of the partnership towards small organisations like SMEs[5].

Today large space firms could take advantage by extending their partnership relations with SMEs in order to acquire more competencies, to share cost of failure with more partners and to share cost of R&D in commercial markets like in telecommunication market. However, we notice that large space firms do not exhibit sophisticated relationships with SMEs like co-design relationships (Haas, Larre & Ourtau, 2001). As SMEs participate in

[4]PERT (Program Evaluation and Review Technique): This method helps to achieve accurate task scheduling.
[5]SME : Small and Medium-sized Enterprise

space manufacturing only at the end of the design phase (Potteck, 1999), we may assume that large space organisations regard SMEs as suppliers rather than partners.

This situation is very interesting if it is linked to our study made in the firm mentioned previously. This firm is a SME and is working for space manufactures and for nuclear plant manufacturers. The design manager said that his team does not conduct co-design activities with space manufactures, but it does with nuclear plant manufactures. If we assume that this SME is not lacking of competencies, we may ask ourselves why large space manufactures do not take advantage of the competencies of this SME, and why they refuse to share the cost of failure and the cost of R&D. An answerer may be found in the following space failure. By the end of the 90s, a French space HRO lost a satellite because a supplier had slightly changed his production processes without validation (Potteck, 1999).

7. Discussion

7.1 Reproduction is an Essential Feature of Risk Management

Space HROs are facing significant levels of risk, because they are operating expensive technical systems in new worlds exhibiting high levels of uncertainty. Space HROs have to manage risk in order to avoid disasters; however this management cannot be conducted during the exploitation phase of space technical systems because it is impossible to fix them when those are in operation. In general, space HROs cannot significantly interact with space probes, satellites and space rockets because they cannot *touch* them. This feature explains why risk mitigation focuses on manufacturing activities and why we assumed that space HROs apply an *ex-ante* risk mitigation where reliability is a major concern.

At the beginning of space exploration, space HROs engaged human and financial resources in order to increase their levels of reliability, whereas now they engage resources rather to maintain the high levels of reliability they have reached. A simple and obvious way to maintain these high levels of reliability is to reproduce the routines which have been validated in successful programs. As we have already noticed, space HROs cannot afford trial and error experimentation and therefore they tend to exploit and refine routines validated in previous programs.

Thanks to a rigorous employment of knowledge codification, space HROs are able to reproduce validated routines in manufacturing activities. In consequence, space manufacturing sometimes exhibits an organisational inertia, because space HROs prefer to maintain validated routines during PPP and in firm relationships instead of exploring new ways in manufacturing activities.

As it significantly helps space HROs to maintain their technical systems highly reliable, this strategy of routines' reproduction is a major feature of *ex-ante* risk mitigation and more generally of risk management when failures are unaffordable.

7.2 The Two-Edged Sword of Reproduction

The major drawback of the strategy of reproduction is summarised by the fact that reproduction can be regard as a *two-edged sword* (Hannan & Freeman, 1984).

HROs try to maintain the high levels of reliability by reproducing the validated routines, however this strategy also may prevent relevant changes. Reproduction of routines may sometimes lead to a kind of rigidity in organisations, because change becomes more and more difficult.

Bach et al (2002, p. 16) underline, that knowledge codification inhibits creativity within organisations. Knowledge codification favours reproduction of validated routines and permits to avoid negative changes. Unfortunately, knowledge codification might not allow positive changes either and so it might deprive firms of solutions which might help to prevent disasters.

Within risky activities, one of the main issue of knowledge codification is the conversion of the relevant tacit knowledge into an explicit knowledge in order to ensure high levels of reliability. However, due to the unclear nature of the tacit knowledge, HROs may make mistakes when they identify the relevant knowledge needed to ensure high levels of reliability.

The characteristics of the "Challenger disaster" have something to do with this type of mistake. According to Vaughan (1990, p. 249), both, the organisation that operated challenger (NASA) as well as the organisation that manufactured the defective component (Morton Thiokol) "were concerned with conserving resources and maintaining established routines". NASA and Morton Thiokol made an agreement in order to "avoid litigation and keep priority on returning the shuttle to flight, and bypasses the question of the company's liability for the accident". It seems that these two HROs did not identify correctly the routines needed to ensure high levels of reliability and they reproduced dangerous routines for safety of astronauts.

However, it would be simplistic to say that all the reproduced routines threaten reliability of technical systems. As the routines are the memory of organisation, it is impossible to assume that all routines implemented by organisation are dangerous without saying that the memory of organisation is dangerous. We consider that the failures does not result from the reproduction of routines in general, they rather result from the reproduction of routines not correctly selected.

7.3 Reproduction Remains Imperfect

When organisations identified the relevant knowledge, namely selected the routines needed to ensure high levels of reliability, they have to perform reproduction. Using the arguments of Nelson and Winter (1982) on the issue of replication, we stress that the reproduction is not cost free and will always remain imperfect due to the tacit knowledge embedded in routines.

Although organisations remember by doing, reproduction of selected routines cannot be regarded as an automatic and natural phenomenon. Routines are the place where the organisational knowledge is stored and organisations use two types of knowledge to conduct their activities, e.g. explicit and tacit knowledge. In order to reproduce the routines selected, space HROs have to reproduce these two types of knowledge.

As the explicit knowledge is already codified, its reproduction is mainly an issue of resources engaged by organisations in reproduction. The more space HROs allocate human and financial resources in knowledge management the more it will be accurately reproduced.

The reproduction of the tacit knowledge is more difficult because is never fully identified even if the organisation regularly uses it. Nobody can ensure that all the tacit knowledge needed will be reproduced and then nobody can ensure that the selected routines will be accurately reproduced. Due to the risky nature of space activities, organisations cannot afford an approximate reproduction of routines. In order to face this constrain, space HROs need to change tacit knowledge in explicit knowledge because it is easer to reproduce.

This change is achieved through a knowledge codification which is not cost free but above all which will always remain imperfect. Indeed, one feature of the tacit knowledge is that some parts of it may remain vague and then it is impossible to change it totally in explicit knowledge. In order words, space HROs cannot ensure that some dangerous variations for reliability will not be introduced during the reproduction of selected routines.

CONCLUSION

Using on the one hand the difference between reaching and maintaining high levels of reliability, and on the other hand the impossibility to fix space technical systems when they are in operation, we stressed that space HROs base their risk management on an *ex-ante* risk mitigation which aims at ensuring high levels of reliability in manufacturing activities. Within this study, we have underlined that reproduction of validated routines is a major strategy of risk management in case of unaffordable failures.

The importance of reproduction has become clear by the strong use of knowledge codification in space manufacturing, and through the tendency of space HROs to maintain the existing routines during the project phase planning and within their firm relationships, although they could reduce time to market and R&D costs.

The strategy of reproduction might be view as a major tool of risk management, however the reproduction sometimes inhibits relevant changes and to reproduce routines can lead to failures. The second major drawback of the reproduction is that it always remains imperfect mainly due to the tacit knowledge embedded in routines.

We noticed that these two drawbacks of the reproduction's strategy are linked through the concept of tacit knowledge. In a future research, it would be interesting to exploit this link in order to analyse more precisely the nature of this strategy. With a focus on the tacit knowledge, we think we could significantly improve the understanding of routines' reproduction and then to provide a suitable framework for risk management in HROs. Indeed, we think we should not use a risk management developed for mass production organisations when we deal with organisations which cannot afford failures.

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REFERENCES

Alcouffe, C. (2001). Formes de coopération interentreprises: l'organisation de la R & D dans l'aéronautique et le spatial LIRHE.

Bach, L., Cohendet, P., & Schenk, E. (2002). Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects. *The Journal of Technology Transfer, 27*(4), 321-338.

Bigley, G.A., & Roberts, K.H. (2001). The Incident Command System: High-Reliability Organizing for Complex and Volatile Task Environments. *The Academy of Management Journal, 44*(6), 1281-1299.

Bourrier, M. (1996). Organizing Maintenance Work at Two American Nuclear Power Plants. *Journal of Contingencies and Crisis Management, 4*(2), 104-112.

Brunier, S. (2006). *Impasse de l'espace: à quoi servent les astraunotes?* Paris: Seuil.

D'Armagnac (2004). *Organisations ephémères et appropriation des connaisances : la mémoire exercée dans les activités projets.* University of Toulouse 1, Toulouse.

Demchak, C. (1996). Tailored Precision Armies in Fully Networked Battlespace: High Reliability Organizational Dilemmas in the "Information Age". *Journal of Contingencies and Crisis Management, 4*(2), 93-103.

Dos Santos Paulino, V. (2006). Stabilite dans l'usage des tic et dans les formes organisationnelles de l'industrie spatiale: quelques éléments d'interpretation. *Gérer & Comprendre,* (86), 27-36.

Haas, J., Larre, F., & Ourtau, M. (2001). R&D dans le secteur aéronautique et spatial: tensions liées à un contexte nouveau. LIRHE.

Hannan, M.T., & Freeman, J. (1984). Structural Inertia and Organizational Change. *American Sociological Review, 49*(2), 149-164.

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision Under Risk. *Econometrica, 47*(2), 263-291.

LaPorte, T.R. (1996). High Reliability Organizations: Unlikely, Demanding and at Risk. *Journal of Contingencies and Crisis Management, 4*(2), 60-71.

LaPorte, T.R., & Consolini, P.M. (1991). Working in Practice but Not in Theory: Theoretical Challenges of "High-Reliability Organizations". *Journal of Public Administration Research and Theory: J-PART, 1*(1), 19-48.

Mannarelli, T., Roberts, K., & Bea, R. (1996). Learnig How Organizations Mitigate Risk. *Journal of Contingencies and Crisis Management, 4*(2), 83-92.

Michot (2004). *Rapport sur l'industrie Aéronautique et Spatiale Française*: French prime minister office.

Nelson, R.R., & Winter, S.G. (1982). *An Evolutionary Theory of Economic Change*. Cambridge: The Belknap Press of Harvard University Press.

Nonaka, I., & Takeuchi, H. (1995). *Theory of Organizational Knowledge Creation.* Oxford University Press.

Perrow, C. (1984). *Normal Accidents: Living with High Risk Technologies*. New York: Basic Books.

Potteck, S. (1999). *La conception de systèmes spatiaux : Système, Paysage, mouvements (Tome 1)*. Toulouse: Editions du Schèmectif.

Ravix, J.T. (2000). *Les relations interentreprises dans l'industrie aéronautique et spatiale*. Paris: Observatoire économique de la défense.

Ritchie, B., & Lallour, G. (1998). L'assurance des risques spatiaux. In F. Ewald & J. H. Lorenzi (Eds.), *Encyclopédie de l'assurance* (pp. 835-861). Paris: Economica.

Roberts, K.H. (1990). Some Characteristics of One Type of High Reliability Organization. *Organization Science, 1*(2), 160-176.

Roberts, K.H., & Bea, R. (2001). Must Accidents Happen? Lessons from High-Reliability Organizations. *Academy of Management Executive, 15*(3), 70-78.

Roberts, K.H., Stout, S.K., & Halpern, J.J. (1994). Decision Dynamics in Two High Reliability Military Organizations. *Management Science, 40*(5), 614-624.

Rochlin, G. (1996). Reliable Organizations: Present Research and Future Directions. *Journal of Contingencies and Crisis Management, 4*(2), 55-59.

Turner, B.A. (1976). The Organizational and Interorganizational Development of Disasters. *Administrative Science Quarterly, 21*(3), 378-397.

Vaughan, D. (1990). Autonomy, Interdependence, and Social Control: NASA and the Space Shuttle Challenger. *Administrative Science Quarterly, 35*(2), 225-257.

Weick, K.E. (1990). The Vulnerable System: An Analysis of the Tenerife Air Disaster. *Journal of Management, 16*(3), 571.

Weick, K.E., & Roberts, K.H. (1993). Collective Mind in Organizations: Heedful Interrelating on Flight Decks. *Administrative Science Quarterly, 38*(3), 357-381.

