Impact of Rare Events on the Strategy of Asset Management

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Abstract
Modern companies operate in a complex business and operational environment. They also face significant uncertainties related to natural, technical, technological, market, organizational, economic, financial, political, and other often intangible influenctial factors affecting their overall management and operations. This context also includes the impact of rare and sometimes disruptive events (natural or human made). Current practices generally neglect taking into consideration both this complexity and the impact of rare events on the strategy of asset management. When those events are considered, traditional methods are normally used in the analysis. However, those approaches and tools have often been unable to adequately capture, characterize and address uncertainties, complexity and the impact of rare events.

This paper proposes an approach regarding the evaluation of the impact of those events on the asset management strategy. A case study demonstrates the applicability of the proposed model.

***Keywords* - Asset Management, Rare Events, Complex Adaptive Systems, Uncertainties**

1 INTRODUCTION

Asset Management (AsM) has become a popular concept among successful organizations in recent years. What does it really mean? AsM is often stereo-typed as being upon maintenance and reliability. Meanwhile, it covers much more than those two areas. The newly published International Standard on AsM ISO55000 provides the following definition: *Coordinated activity of an organization to realize value from assets* [ISO, 2014]. The same Standard defines an asset *as an item, thing or entity that has potential or actual value to an organization*.

As per good practices, AsM should not only focus on the asset itself, but on the value that an asset can provide to the organization. It involves the balancing of costs, benefits, opportunities and risks against the desired performance of assets, to achieve the organizational objectives. The balancing might need to be considered over different both timeframes and the spatial scales. AsM interacts with many functions of an organization. In fact, AsM should focus on the total business impact [IAM, 2012].

Concurrently, enterprises operate in a business, natural, technical, technological, organizational, regulatory, legal, political, financial, and market environment (hereafter called business and operational environment) that is characterized by significant intrinsic uncertainties.

Additionally, contemporary companies perform their business in the modern world which is tightly connected at numerous levels and in different ways. The latter are quite favorable for normal business, but may reveal damaging effects in cases of major perturbations in markets, finances, energy supply, political unrests, etc. Analyzing and handling those issues through traditional methods has recently shown to be inefficient. It is generally due to a lack of knowledge regarding the type and range of uncertainties, the nature of interconnections, the level of complexity as well as our low ability to predict future events and their characteristics [Makridakis et al., 2009; Makridakis et Taleb, 2009a, 2009b; Mendonça et al., 2009; Muller, 2010].

Hence, the modern world is complex, and companies operate in a complex business and operational environment. In addition, companies themselves are complex by their management, organizational and operational structure (particularly the large ones), which adds to the overall complexity and uncertainties.

In such a context, they are exposed to various natural, technical, market and human made extreme and rare events which may seriously perturb their current and long-term performance.

Thus, we need to optimize the balance between short term and long term goals, between costs, risks and performance outcomes, between capital investment and subsequent operating costs, between asset utilization and asset care (reliability, availability, maintenance) taking into account the complexity of their business and operational environment.

The impact of rare events on AsM strategies and related decision-making is nearly not considered in research works despite the importance of this topic.

So, the present study aims at developing a methodology for identification, characterization and treatment of rare events in asset management strategies.

In this study, we argue that the business and operational environment should be approached as a complex adaptive system (CAS). Consequently, the overall asset management strategy should be considered and analyzed as a CAS.

2 LITERATURE REVIEW

The current research integrates several fields of expertise such as asset management, the analysis of rare events and the theory of complexity. The literature review below summarizes some important contributions in these areas.

2.1 Asset Management

The concept of Asset Management is emerging as a 'mainstream' expectation for competent organizations, and it is relatively young discipline. It has generated significant interest across various industries and is still maturing [IAM, 2012]. The previously mentioned Standard ISO 55000 represents an industries-wide consensus in this area for the time being. It is undergoing its implementation and maturing.

The nuclear power industry has invested significant efforts in elaborating asset management approaches and methods tailored for its needs and particularities. The work has been mainly performed through Electrical Power Research Institute (EPRI), Institute of Nuclear Power Operations (INPO), Nuclear Energy Institute (NEI), utilities, regulatory bodies, as well as numerous universities and various research institutions.

This industry has basically developed Nuclear Asset Management (NAM) process of making operational, resource allocation, and risk management decisions at all levels of a nuclear generation business to maximize nuclear power plant value to stakeholders, while maintaining safety to the public and the plant staff [EPRI, 2007].

The nuclear power industry has also elaborated Risk-Informed Asset Management (RIAM), which is a composite financial/engineering method complementary to NAM that uses risk management approach to support equipment long-term planning and investment decisions at the corporate, fleet, plant, system, or equipment levels of nuclear power organizations. [EPRI, 2005; EPRI, 2002].

Some other industry specific processes have also been elaborated. Petrochemical industry has developed its AsM since late 1980s [Komljenovic, 2014]. Power generation, transmission and distribution utilities are elaborating their specific AsM [Adoghe et al., 2013; Catrinu et Nordgard, 2011; Dashti et Yousefi, 2013; Komljenovic, 2014]. The management of infrastructures has used this concept for many years [Doman, 2002; Komljenovic, 2014]. The transportation industry has also performed some works in this area [Ballis et Dimitriou, 2010; Doman, 2002]. The mining industry starts elaborating some methods related to asset management as well, but it is at a very beginning [Cornford, 2014; Komljenovic, 2007].

2.2 Impact of rare events

Considering that AsM is continuous and long-term activity of an organization, forecasting all relevant influential factors of their business and operational environment is vital for practically all technical, economic and business decisions, and represents a key part of a sound decision-making. It should also include the consideration of impact of extreme and rare events.[1]

The definition of a rare event may seem intuitive, but the experience shows that it is not so obvious. Fowler and Fisher propose a working definition which is considered in the current study: *"A rare event is an event that current thinking, knowledge, models, and methods dismiss, ignore, overlook, or marginalize as something that practically speaking will never happen and hence fail to predict, but which actually has a significant non-zero probability of occurring and when it does, may well be catastrophic"* [Muller, 2010]. Indeed, these events cannot adequately be statistically characterized by using the extreme value theory.

Muller [2010] stresses: *"Decision makers in both the public and private sectors, as well as analysts, engineers, and scientists must understand that it is no longer acceptable to consider rare events as external to their design, analysis, and operating plans... An event starts as rare and completely unexpected—Taleb's "Black Swan"—and ends as tamed through prediction, mitigation, or even prevention to the point that it is no longer a black swan."*

"Black Swan" or rare events were introduced and analyzed by Taleb in his book on this topic [Taleb, 2010][2]. He has already discussed this matter in an earlier book on the randomness [Taleb, 2005]. Initially thought to cover financial markets, the idea of Black Swan extended the metaphor to events outside of financial world. He also indicates that Black Swan (rare) events mostly happen in complex systems.

Their occurrences often yield undesirable cascading effects that are very challenging to deal with. Several authors and studies consider that they should be seriously taken into consideration in engineering and business analyses [Aven, 2014; OECD, 2011; Muller, 2010].

Mendonça et al., [2009] consider ways in which radically uncertain and disruptive events may be introduced into corporate decision-making structures. They introduced the concept of

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[1] Those events may include but are not limited to natural disasters, financial and market crashes, major failures of critical assets, major industrial accidents, prolonged shortages of power/energy supply, political unrests and instability, armed conflicts or terrorist attacks, radical changes in regulatory framework, extremely negative treatment in mass-media, major legal pursuits, etc.

[2] Definition of a "Black Swan" event such as provided by [Taleb, 2010]: first, it is an outlier, as it usually lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact. Third, in spite of its outlier status, human nature tries to elaborate explanations for its occurrence after the fact, making it explainable and predictable.

‘‘wild cards’’ which refers to trend-breaking/trend-creating rare events that are very hard or even impossible to anticipate, but that should nonetheless be expected in complex and fast-evolving environments. The discussion is based on the experience obtained in two strategic projects carried out in two industries – civil aviation and investment banking.

There are no scientific publications that analyse the impact of rare events on the AsM strategy.

2.3 Complex Adaptive Systems and Complexity Theory

How do rare and disruptive events occur? They may be interpreted as a result of our major lack of knowledge upon the real nature of phenomena under study or observation. It implies that epistemic uncertainties related to those events are significant and poorly understood. As previously highlighted, several studies analyzing rare events explicitly or implicitly consider that they mostly occur in complex systems and situations since we are unable to entirely comprehend them.

In principle, a combination of unusual circumstances should come together to a rare event taking place. However, the increasing degree of interconnectedness in complex organizations, systems and structures in the modern world is making these circumstances more likely to occur. What complex systems are? How do we describe and model them? The review hereafter provides basic insights on this topic.

The complex systems or complex adaptive systems (CAS) are dynamic systems able to adapt in and evolve with a changing environment. They exhibit coherence under change, via conditional action and anticipation, and they do so without a strong central direction. The CAS are self-organizing, evolving, dynamic, rarely predictable, and not proportional nor additive. It is important to recognize that there is no strict separation between a complex system and its environment [Chan, 2001; NISAC, 2015; Current, 2000].

The CAS may function at various time scales (from seconds to years or decades), and at multiple spatial scales (from less than one millimetre to several kilometers or more). Orrell et McSharry [2009] state that complex systems cannot be reduced to simple mathematical laws and be modelled appropriately. This position is also shared at some extend by Farmer [2012] and Aven [2014].

A new interdisciplinary field called *Complexity Science* or *Complexity Theory* has emerged and evolved over last few decades seeking to understand, predict, and influence behaviors of complex systems. It looks for to develop concepts, methods and tools that transcend specific applications and disciplines [Farmer, 2012]. In this context, the Institute Santa Fe was created in the early 1980s aiming at discovering, comprehending, and communicating common fundamental principles in complex physical, computational, biological, and social systems [Santa Fe, 2015]. This discipline deals with issues that traditional science has previously had difficulty addressing such as non-linearity and discontinuities, self-organization, emergence, aggregate macroscopic patterns rather than causal microscopic events, probabilistic rather than deterministic outcomes and predictions, change instead of equilibrium [OECD, 2009, 2011].

There is no commonly agreed definition of complexity science. For example, University of Southampton and its Centre of Complexity Science Focus proposes a definition which may be reasonably acceptable: *“Complexity science is the scientific study of complex (adaptive) systems, systems with many parts that interact to produce global behavior that cannot easily be explained in terms of interactions between the individual constituent elements”* [University of Southampton, 2015].

The complexity science helps reframing our views of CAS which are only partially understood by traditional modelling techniques. Thus, it offers an alternative and complementary view of the real world.

For performing analyses in this field, several methods and tools have been developed and used such as Multi-Agent Based Models and Network Analyses. Additional complexity-related techniques are also employed although their use is not unique to complexity science: Data Mining, Scenario Modelling, Dynamical Systems Modelling, Artificial Intelligence, Neural Networks, Evolutionary Game Theory [OECD, 2009, OECD, 2011; EPRI, 2004; Farmer, 2012; Kremers, 2012; NISAC, 2015].

3 MODEL FOR CHARACTERIZING THE IMPACT OF RARE EVENTS ON ASSET MANAGEMENT STRATEGY

3.1 Global model of the strategy of asset management

The asset management strategy is composed of an array of interacting and interdependent activities and constituent elements in a multilevel structure. It should be closely linked to the strategic planning of an enterprise. In spite of numerous research works in this area, there are still opportunities to further expand our knowledge in this field. We believe that new concepts and approaches should take into account more systematically the overall complexity of business and operating environment.

In addition, enterprises are part of larger societies, structures, systems and entities, each with their own people, processes, organisational structure and rules, technologies, markets, resources, legal constraints, and ways of carrying out business. There are elements that individual enterprises may efficiently predict and control (mostly technical and technological systems within them). Other factors may be rather efficiently influenced and directed, but not necessarily tightly controlled by a company (e.g. enterprise-wide structure and organisation, way of performing business activities). The prediction of those factors is more difficult due to associated uncertainties and complexities. Finally, there are all other elements representing the environment of enterprises that they cannot accurately predict, control or strongly influence (e.g. natural, business, regulatory and political environment, market conditions). However, those factors usually exercise both a strong influence and a major impact on their operations and overall performance. Due to an unpredictability of this environment, rare events occur in this context exercising a major impact on the strategy of AsM, and the overall performance of an enterprise. Figure 1 depicts the hierarchy of this global operational and business context.

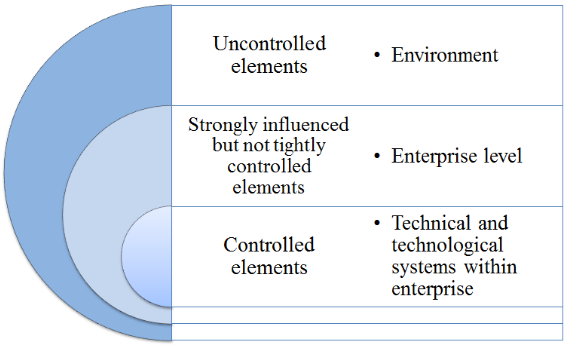

Figure 1: Business and operational environment of an enterprise

Thus, it is necessary to develop a theoretical conceptual model for the asset management strategy that identifies and captures key constituent elements and influential factors, as well as their relationship, interdependencies and complexity. One of the means consists of considering contemporary enterprises and their strategy of AsM as complex adaptive systems (CAS).

We propose a global model of the strategy of asset management which integrates all relevant engineering, natural, operational, organisational, economic, financial, as well as other quantitative, qualitative and intangible influential factors in a structured and systematic manner. The impact of uncertainties and complexity of business and operational environment is systematically taken into consideration. Such integrated model has not been considered in existing studies in this field.

The approach can also take into account the impact of rare events in the overall strategic and asset management decision-making. This aspect has been usually neglected in both existing research works and practice despite the fact that those events could have severe consequences for an enterprise.

The proposed approach is intended to be generic, applicable and adaptable to any size and any type of companies. However, we should emphasize that it is suggested for the strategic and asset management decision-making process affecting both mid and long term performance, and sustainability of an enterprise.

Figure 2 presents a proposed high-level global model which consists of six sub-models:

1. Market and revenue sub-model (predominantly external to an organization, but has a major impact on its global performance; this constituent element may not be efficiently controlled or influenced by an enterprise),
2. Sub-model of reliability, availability and maintenance (RAM) factors (mainly internal to an enterprise, in principle, it may well control and influence this element)
3. Sub-model of operations and operational constraints (mainly internal to an enterprise; it may be controlled and strongly influenced),
4. Cost sub-model (both internal and external to an enterprise; it may be partly controlled and influenced),
5. Organisational sub-model (mainly internal to an enterprise; it may be partly controlled and efficiently influenced), and
6. Sub-model of impact regarding other often less tangible influential factors such as regulatory requirements, socio-economic impact, political factors, environment protection, security, public risk perception, media treatment, etc. (mainly external to an organization, but it has a major impact on its global performance; normally, this factor cannot be efficiently controlled or influenced by an enterprise).

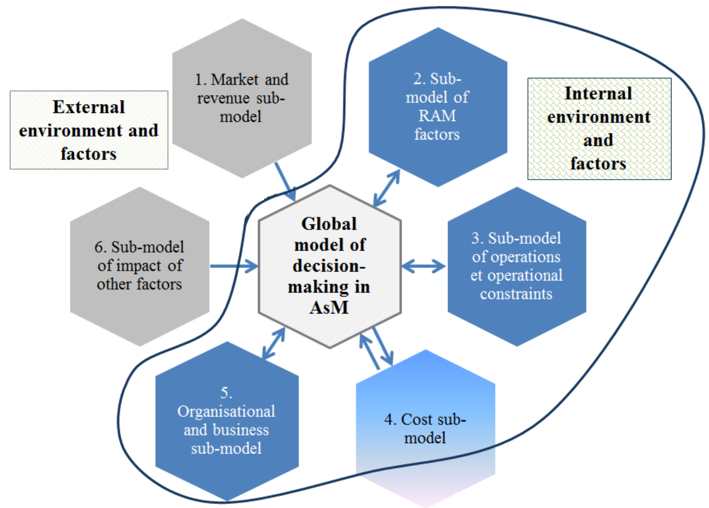

Figure 2: Global model of the strategy of asset management

These sub-models and their constituent parts interact in a complex manner, and lead to the behavior of the global model (system) that is not obvious from the individual behavior of its elements. The latter are complex themselves as far as their structure, management and functioning are concerned. So, the strategy of AsM of an enterprise may be considered to be an emergent phenomenon integrating several functional, operational, and management layers. It involves numerous feed-back loops reacting to both influences of their environment and the behavior of other constituent parts usually creating a non-linear and adaptive behavior of the whole system. If any of interacting processes or elements is changed or experiences variations, the functioning and performance of other elements and the entire system may be seriously altered.

Therefore, the proposed global model enables to continuously take into consideration and to integrate the overall feedback from its sub-models and their constituent parts. It also includes the impact of the organisation’s strategic orientation, the occurrence of extreme and rare events as well as stakeholders' requirements and expectations (Figure 2).

3.2 Model for characterizing the impact of rare events on the strategy of asset management

The model for characterizing the impact of rare events on the strategy of asset management proposes a consequence based approach. The experience and various research works have shown that it is nearly impossible to accurately calculate small probabilities of occurrence in connection with rare events. They are grossly either overestimated or underestimated. How could we precisely determine whether likelihood is 10^{-8}, 10^{-9} or 10^{-10}? We may easily miss several orders of magnitude given huge epistemic uncertainties involved there. On the other hand, we are of opinion that we cannot ignore the impact of those events in asset management strategies of contemporary companies due to their complex business and operational environment.

A major challenge in analyzing the impact of rare events on asset management strategies is related to the need to understand the way in which constitute parts are interrelated, and what their vulnerabilities to those events are. At initial stages, the mapping through an expert elicitation is a suggested approach for analyses. For this purpose, the global process depicted in Figure 2 may serve as a starting point. Another challenge concerns a thorough understanding of each sub-model, its own complexities and interconnections. These two issues lead to a new challenge related to a significant effort to perform an initial analysis and mapping as well as to keep them up to date since the whole process and structure evolve over time [OECD, 2011]. Further stages of more sophisticated analyses involve the modelling of the impact of rare events using techniques of complexity science.

To improve the understanding of CAS, maps need to identify both critical components and interactions between those components within the system, such as interdependencies, nodes, hubs, pathways, and external/internal influential factors etc. This way, one may discover major potential vulnerabilities in the system related to rare events, and propose adequate preventive and mitigation measures. Delphi method and a structured expert elicitation are indispensable tools in identification of credible rare events, and estimation of the severity of consequences.

In the present study, 26 various types of potential rare events have been identified and proposed (natural, technological, technical, market and human made). They are presented in Appendix 1. Table A1-1 depicts the proposed list of those events which should be taken into consideration while estimating their impact on the asset management strategy. It also includes the identification of potential business opportunities arising from the occurrence of rare events. The evaluation should identify potential precursors of those events as well as thresholds from which an event may be considered as a rare one. Those thresholds should be expressed in physically measurable terms as far as possible. It is worth mentioning that the list presented in Table A1-1 is not exhaustive, and may be extended or reduced as a function of a specific organization's context.

As far as consequence categories are concerned, the study proposes nine categories. Table A1-2 provides more detailed description of each category and the levels of consequences (catastrophic, severe, major, and minor).

4 CASE STUDY

The impact of rare events on the asset management strategy is illustrated through the case of some Hydro-Québec's assets. Hydro-Québec is one of largest North American companies which generates, transmits and distributes electricity. Its sole shareholder is the government of Quebec. HQ uses mainly renewable generating sources, in particular large hydro units, and supports the development of other technologies—such as wind energy and biomass [Hydro-Quebec, 2015a].

We have performed an analysis with regard to the impact of rare, unanticipated events leading to the abandon of the Gentilly-2 Nuclear Power Plant (NPP) Refurbishment Project in 2012. The G2 NPP was the sole Hydro-Quebec's nuclear generating utility. It was a CANDU6 nuclear power plant and has been designed for a 30 year service life or more accurately 210 000 Equivalent Full Power Hours (EFPH) as it is the case of all the CANDU nuclear generating stations [Canteach, 2015]. It started its commercial operation in 1983, which should have reached this limit somewhere in 2013. For that reason, Hydro-Quebec has initiated prefeasibility studies in the early 2000s in order to examine the possibility to refurbish the station, and to extend its useful life for another 30 years. In these years, a general trend in the nuclear power industry was oriented toward an extension of operations beyond the initial service life. It was based on an accumulated operational experience and new scientific insights which showed that it is possible. Following those studies, Hydro-Quebec made a positive decision in 2008 to refurbish the station. Required engineering and field works have started under the Refurbishment Project. The cost of those activities has been estimated at 1.9G$, and the refurbishment work should have started in March 2011. The planned restart was foreseen for November 2012 [Hydro-Quebec, 2015b].

However, after initial works began, the Refurbishment Project has been delayed several times. Finally, Hydro-Quebec announced on October 3, 2012 the closure of the Gentilly-2 NPP at the end of 2012, and its decommissioning. The Gentilly-2 NPP ended its commercial operation on December 28, 2012 [Hydro-Quebec, 2015b, 2015c].

What has happened within four years from the initial positive announcement to the abandon of the project of such magnitude?

It appears there were a series of unanticipated and rare events which finally contributed to overturn the initial decision. Such events represent important epistemic uncertainties for a decision-making process. They are almost impossible to predict, and to mathematically characterize in a complex operational and business environment.

This study illustrates how unanticipated and rare events and their unfavorable combination have the capability to entirely change or disrupt major decisions regarding asset management within a relatively short period of time. Table 1 provides a summary overview of the analysis.

Table 1: Summary analysis of the impact of rare events on the G2 Refurbishment Project

No	Description	Affected sub-model (Figure2)	Category in Tables A1-1/A1-2	Comment
1	Extreme market and financial crisis 2008/2009	1	(3, H, MJ)*	Created a unfavorable business environment
2	Unforeseen increase of shale gas production in the U.S. in late 2000s, natural gas price decrease [EIA, 2015]	1; 6	(17, H, MJ) (18, H, MJ)	New, unfavorable market conditions
3	Unanticipated major technical difficulties in refurbishment of PLGS and Wolsong NPPs (2008-2012) [WNN, 2010, 2011]	2; 6	(6, D, CT) (23, E, MJ)	A negative feed-back decreased confidence in the feasibility of the refurbishment
4	Significant cost overruns regarding the G2 refurbishment project	2; 3 4; 5; 6	(6,D&H,CT) (23, E, MJ)	Direct negative impact

No	Description	Affected sub-model (Figure2)	Category in Tables A1-1/A1-2	Comment
	(from 1.9G$ to 4.3G$) [Hydro-Quebec, 2015b]			related to cost overruns
5	Extreme natural disaster (earthquake and tsunami) in Japan resulting, among other things, in Fukushima Daiichi nuclear accident. The later resulted in more strict regulation and a wider public opposition to the nuclear power generation (natural, regulatory, economic and public perception influential factors) [INPO, 2012]	5; 6	(1,A-I, CT) (22, F, SV-MJ) (23, E, CT)	Overall negative effect on all the categories of the impact due to both actual damages and public perception
6	Political changes; newly elected Government of Quebec in September 2012 was unfavorable to the G2 refurbishment (impact of political factors) [PQ, 2012]	6	(25, H, MJ) (25, H, CT)	- Corporate level impact - Plant level impact (closure of the NPP)

*) Legend:
(3, H, MJ) – (3) – Number of event in Table A1-1 (Financial and market crashes); (H) – Category of impact in Table A1-2 (Strategic Plan); (MJ) – Severity of consequences in Table A1-2 (Major)

It should be highlighted that the coincidence and the combination of these six unanticipated, rare events resulted in a non-linear amplification of their aggregate effect. The latter is considerably superior to the simple sum of their individual effects. The analysis clearly demonstrates that the overall context of the G2 Refurbishment Project as an AsM strategy can be considered as a CAS in which a series of rare events produced an adverse outcome. Thus, a major AsM project, initially approved in 2008, was abandoned four years later.

5 Conclusion

Facing tough competition, companies worldwide are constantly forced to produce more at lower cost. They are also confronted to a highly complex business and operational environment which also includes intrinsic uncertainties related to business, natural, technical, technological, organizational, regulatory, legal, political, financial, market, and environment influential factors. The strategy of asset management plays a key role in this context.

In such a perspective, industries tend to develop various processes and approaches, which may enable efficiently addressing these issues. They are often based on traditional approaches which are generally unable to adequately grasp and tackle complexities and uncertainties. It is particularly true while considering rare, unanticipated events which have capabilities to disrupt strategic activities or even jeopardize the survival of organizations.

The paper claims that the modern enterprises and their strategy of asset management should be considered as complex adaptive systems (CAS) which should modeled through various tools and methods of complexity science such as Multi-agent modeling or Dynamic simulation. In such systems, the occurrence of rare events is very plausible since we do not entirely grasp the scope and nature of associated uncertainties and connexions between their constitute elements.

This study presents initial results on how to take into account rare events in the strategy of asset management. The consequence based method is proposed. Further research work should be directed to a better understanding of the complexity of AsM and the development of various models using different techniques of complexity science.

Such an approach may assist decision-makers in key decision-making processes and asset management by providing more realistic insights. The proposed method may easily complement existing traditional approaches. It also intends to integrate them into a holistic process.

A case study carried out under this angle regarding the abandon of Gentilly-2 NPP Refurbishment Project at Hydro-Quebec demonstrates the relevance of considering more systematically the complexity and the impact of rare events on the strategy of asset management.

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Appendix 1: Categories of rare events, and severity of consequences

Table A1-1: Work Table for identifying rare events relevant to the strategy of asset management

No	Main extreme event (hazard)	Detailed description	Applicable		Precursors/threshold	Impact on critical assets and asset management (Table A1-2)[3]					Describe business opportunity if any	Mitigation measure exists		Speed of change		Duration of the impact						Level of spatial impact					Description of new mitigation measure if required	Deadline	Responsible	Comment
			Y	N		CT	SV	MJ	MI	N/A		Y	N	Sudden	Emerging	Instant	1-2 days	Several days	1-4 weeks	Several months	One year or more	Installation or plant	Local	Regional	National	International				
1	Natural disasters	Earthquake																												
		Volcano																												
		Tsunami																												
		Landslide																												
		Geomagnetic storms																												
		Other																												
2	Severe/extreme weather conditions	Hurricanes																												
		Winds																												
		Tornadoes																												
		Droughts																												
		Lightning																												
		Rain																												
		Floods																												
		Global warming																												
		Other																												
3	Financial and market crashes																													
4	Major economic crisis/depression																													
5	Major industrial accident																													
6	Major failure/loss of critical assets																													
7	Major technical difficulties																													
8	Cyber attack																													
9	Industrial spying causing loss of intellectual properties																													
10	Loss of key expertise (technical or management)																													
11	Major labor conflict																													
12	Loss of key suppliers																													

[3] Legend: Categories of the severity of consequences (Table A1-2):

CT – catastrophic
SV – severe
MJ – major
MI – minor

No	Main extreme event (hazard)	Detailed description	Applicable		Precursors/threshold	Impact on critical assets and asset management (Table A1-2)[3]					Describe business opportunity if any	Mitigation measure exists		Speed of change		Duration of the impact						Level of spatial impact					Description of new mitigation measure if required	Deadline	Responsible	Comment
			Y	N		CT	SV	MJ	MI	N/A		Y	N	Sudden	Emerging	Instant	1-2 days	Several days	1-4 weeks	Several months	One year or more	Installation or plant	Local	Regional	National	International				
13	Unavailability of key raw materials (extreme supply disruption)																													
14	Prolonged loss of power or energy supply																													
15	Development of entirely new technologies or products by competitors																													
16	Advent of new strong competitors																													
17	Major legal pursuits																													
18	Payment default of major customers																													
19	Loss of major customers																													
20	New laws and regulations radically changing regulatory/legal environment																													
21	Extremely negative treatment in mass-media causing an unfavorable business environment																													
22	Extreme public opposition to activities (project)																													
23	Political changes and conflicts	Lasting political turmoil																												
		Terrorist attacks																												
		Wars and armed conflicts																												
		Economic sanctions																												
24	Pandemics																													
25	Other																													
26	Credible combination of events (1)																													
27	Credible combination of events (2)																													

Table A1-2: Severity of consequences

Category of impact	Impact on:	Severity of consequences			
		Catastrophic (CT)	**Severe (SV)**	**Major (MJ)**	**Minor (MI)**
A	**Security and health of people (workers and/or general population)**	Death of one or several persons	Severe injuries and/or permanent disability	Injuries without permanent disability ; major and observable loss of quality of life	Minor injuries, minor loss of quality of life
B	**Environment**	Destruction of habitats, and death of numerous animals.	Mass destruction or contamination of habitats. No death of animals or very little	Destruction or contamination of habitats near the site.	Minor contamination of habitats. No destruction of habitats
C	**Material goods, physical assets (own and/or others, population) - damage (or cost of reconstruction)**	Destruction of properties over an area exceeding the limits of the site. Damage more than $10M	Significant damage to own physical assets, destruction of private properties off site. Damage between $2M and $10M	Substantial damage to the site and minor to moderate off-site damage. Damage between $100k and $2M	Minor to moderate damage to the site. Less than $100k damage
D	**Increased costs/work schedules**	Increase in cost / schedule 100% and more	Increase in cost / schedule between 50% and 100%	Increase in cost / schedule between 15% and 50%	Increase in cost / schedule less than 15% (covered by the contingency plan)
E	**Impact on the reputation and image of the company and/or industry**	Very negative impact at national or international level. Focus of national and international media more than 5 days	Local or regional considerable negative impact. Focus of national and regional media for several days	Local, limited negative impact. Focus of regional media for several days	Little or no negative impact. Local complaint or a single article in a local media
F	**Regulatory impact**	Noncompliance or non-respect of applicable laws and regulation Civil litigation, criminal accusations Completely new regulation, legislation	Violation of an article or regulation that could lead to a fine Very significant changes in existing regulation, legislation	Violation of an article or regulation without fines Major changes in existing regulation, legislation	Small regulatory impact or no impact Minor changes in existing regulation, legislation or no changes
G	**Loss of production**	Three weeks or more of downtime Cutting production more than 60%	Downtime between three days and three weeks Production cuts between 40% and 60%	Downtime less than 3 days Production cuts between 15% and 40%	No downtime Cutting production less than 15%
H	**Impact on the strategic plan**	Completely or almost completely invalidates the strategic plan	Major changes needed in the strategic plan	Moderate and limited changes needed in the strategic plan	No significant impact on the strategic plan
I	**Level of implementation of emergency measures**	Activation of large-scale emergency measures; evacuation of the population at regional level	Activation of emergency measures at local level; evacuation of the very limited population (local population)	Activation of emergency preventive measures or warnings; no evacuation of people	Activation of emergency measures is not necessary