RISK MANAGEMENT FOR MÉGA-PROJECTS

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ABSTRACT

Exceptional by their intrinsic characteristics, mega-projects are also exceptional by the number of partners, companies, political authorities or environment issues that they associate in a common context. To each of those identities correspond a certain number of risks that have to be evaluated, quantified, prioritised and finally minimized. Those requirements concern the mega-structure reliability but also its consequences for the users, the neighbours or local inhabitants, the project environment and technical, economical and financial associated partners.

To be efficient and adapted, risk management processes should be integrated since the very beginning of the project, within the planning and design phases, and should be pursued at the construction and operation phases. Risks anticipation and continuity in risk management from one stage of the mega-project to the other have proved to be key elements in the success of the operation. Integrated risk management is a more and more determining factor the definition of design choices such as architecture choices, materials choices, construction method and therefore costs.

1. MEGA-PROJECT DEFINITION AND CHARACTERISTICS

The mega-project term generally states for projects internationally recognized to be exceptional because of their dimensions, cost, architecture or technical specificities. Yesterday's San Francisco Golden Gate and Oakland Bay Bridges, today's Millau Viaduct in France, Rion-Antirion Bridge in Greece, Akashi Kaikyo Bridge in Japan or Storebaelt Tunnel in Denmark and maybe tomorrow's upcoming Messina Bridge between Italy and Sicily are obvious examples of mega-projects.

From an engineering perspective, the definition of mega-projects is quite subjective and generally refers to projects associating great volumes (dimensions, costs) and technicity. Architectural challenge as well as difficulties relative to the site can thus lead to this definition, independently from size considerations. In terms of dimension and cost considerations, one can consider bridges of total length greater than 1000 meters and global cost higher than 100 millions euros (120 M USD) and tunnels of total length greater than 10 km and global cost higher than 500 millions euros (600 M USD) as mega-projects. For what concerns bridges, the proposed definition can be made more accurate considering the span length which is more representative of the achieved technical performance instead of the total length. The mega-project definition can also be extended to an entire section of any road network (for instance city ring roads, highways, etc…) and will include in this case the whole road infrastructure, including bridges, tunnels, environmental insertion, etc. Moreover, mega-projects qualification can vary with the size and impacting domain of the responsible authority: State, county, city… And it can also differ from one country to another, depending on the level of development and techniques: mega-projects definition will for instance apply to different structure characteristics depending if it is built in a developed country or in a developing country.

From a manager or owner perspective, mega-projects are essentially defined in terms of costs, cash flow, organisation, planning and responsibilities towards users and project environment. As an example, the American Federal highway Administrations define mega-projects as projects with total estimated cost greater than 500 M USD and which receive federal financial assistance because of their importance in public or congressional attention and because they have extraordinary implications for the national transportation system [1].

Finally, the mega-project definition can be extended to any project, considered of exceptional characteristics (cost, dimensions, architecture, technique) or because it is particularly exposed to some natural or manmade risks. The exceptional attribute is to be defined relatively to the responsible authority or company. Exceptional by their intrinsic characteristics, mega-projects can also unfortunately happen to be exceptional by the size of the disasters they can engender when risks or not or badly managed. The next paragraph aims to provide general framework and guidelines risks management in mega-projects.

2. RISK MANAGEMENT FRAMEWORK FOR MEGA-PROJECTS

2.1. Factors and partners associated with risk management in mega-projects

Mega-projects have the particularity to associate in a common context many partners, companies, political authorities or environment issues, the culture, the critical objectives and considerations of which can differ and sometimes be incompatible. Mega-projects construction works involves risks for all parties directly and often indirectly involved in the project. By their nature, they also entail considerable risks for the owner. Often the project scope or ambition level will change during project development and implementation. Changes may be due to uncertainty at the early project stages for example on the exact corridor, the technical standards, project interfaces or the geotechnical and environmental conditions. Significant cost overrun and delay difficulties may arise from these uncertainties. In addition, there is a potential for large-scale accidents during mega-project work and, for mega-projects in inhabited areas, there is a risk of damage to a range of third party persons and property. Finally there is a risk that the course of the project may be affected by public protest and political reactions arising from the problems that the mega-project may cause to the public.

Figure 1 below presents the general framework and associated partners that are directly or indirectly connected to mega-projects. For each of them, risks are to be considered in both ways: risks induced by the project on its environment (natural or human) and risks induced by the context on the project.

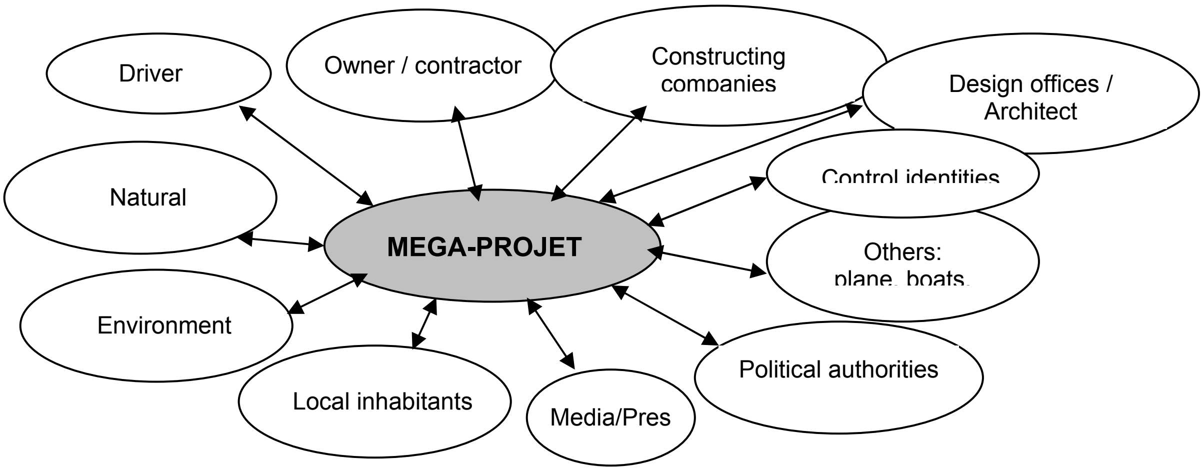

Figure 1: Mega-project framework and associated partners

The drivers are the main users of the infrastructure. Their relation to the mega-project is associated with different sorts of risks: financial risk first as the cost effectiveness of the project is directly dependent on its attractiveness (opportunity studies, time saving, comfort); risk related to the drivers security then because a badly designed or poorly equipped road structure is susceptible to endanger users' life or health (accident predisposing profiles, deficient crash barriers, ill-functioning fumes extractors inside tunnels, etc…). Conversely, an accident caused by a careless driver can damage the structure and reduce its serviceability (fires in tunnels, crashes on barriers, dangerous goods pouring…).

The owner (or the contractor) are the ones who finance the upcoming infrastructure. Their main issue is therefore generally associated to financial risks, construction delays, risks related to operation phases and structural ageing. However they are also increasingly concerned with issues related to moral and juridical responsibility towards drivers and environment all along the structure service life (or contracting time). Since 1976, European legislation for instance has defined six basic requirements to oblige public owners to be concerned with risks and environment and to account for the public command socio-economical and juridical consequences [2]. As far as public infrastructures and their components are concerned, we will mention requirements dealing with structural resistance, security (construction related risks, service related risks, fire resistance), as well as protection (hygienic working conditions, health protection, noises, environment), and saving (energy, isolation)… The new normalization approach thus moves from a descriptive approach to a performing approach. Therefore, public owners have to make choices in terms of results instead of means. At the same time, the Eurocodes do not anticipate on owners choices. For instance, they do not fix the risk assumptions but are just aimed at describing the methods to take them into account. So to say, the Eurocodes considerably increase owner's responsibility as they do not allow them to rely exclusively on engineers [3].

Architects, design offices and constructing companies are in charge with design and construction of the structure. They are therefore involved in all related to these critical phases of the project: financial risks, construction delays, work accidents, construction quality, respect and protection of the environment… An unsatisfying risk management during those stages might hazard the completion of the project on times but also the standing and the financial health of the company. In the same way, contributions of independent, qualified control organisms are indispensable conditions of success.

Depending on its implantation site, mega-project can be exposed to several natural constraints of climate nature (wind storm, hurricanes, rain, snow, cold, ice-storm, aggressive ambient atmosphere…), geotechnical nature (landslides, rock falling…), hydrologic nature (floods…) or seismic nature (earthquakes, liquefaction, tsunami…). On the contrary and more rarely, a mega-project, because of its dimensions, can modify those levels of constraints by altering the site geomorphology. It is sometimes the case for instance for large dams or tunnels that can generate small earthquakes, rock fallings, slope instabilities, floods…

Due to their dimensions, mega-projects directly and fatally impact environment. Environmental aspects are increasingly critical political and social preoccupations in many countries. They gather several issues such as site ecology (fauna, flora, protected species, pollution, water, noise…), landscape insertion, architecture, historic buildings proximity or archaeological remains. Project studies must therefore anticipate on a certain number of environment protection measures (or eventually counter-measures) as well as adapted communication campaign. If not, the owner may face public contest and political authorities and ecologic associations disapproval, resulting in delays and difficulties in acquiring land, right-of-entry for land parcels or construction work disruption.

On the same idea, local inhabitants and politics are directly concerned by risks related to mega-project construction (noise disturbs, pollution risk, traffic disruption, modification of the social-economical environment, housing cost, media coverage and pressure…). A good adapted communication campaign is once again essential. Rail transportation domain is for instance very concerned on this matter. Many preventive dispositions are thus undertaken in order to prevent any derailment close to civil structures like buildings, train stations, bridges that might have very bad consequences in terms of image. In the road domain, negative image effects can also result from highway closing, population evacuation, within tunnel fires or catastrophic accidents. Consequences of an accident must therefore be considered not only through the technical perspective (structural integrity) but also through the social-economical and sometimes political angle (drivers disturbance, risks for local environment) [3].

Lastly, the mega-project can be endangered by any other type of hazard, more or less predictable or anticipated, such as ship collisions, aircraft crashes, terrorism, the consequences of which are most of the time dramatic for the infrastructure as well as implicated third party.

For what concerns drivers and environment in particular, one will note that risks must be established, analysed and evaluate not only for the construction and service opening periods but for all along the expected service life of the structure. Risk management in mega-projects must therefore not only represent an answer to nowadays people needs and preoccupations but also anticipate on those of future generations, thus responding to the nowadays worldwide recognized and shared concern of "sustainable development".

Major projects of road infrastructures thus demand a balancing of various factors such as financial management, planning and design, right-of-way, construction management, environmental impact, safety and traffic operations, future operations and maintenance, and public relation. Populations sensitivity to one or the other of those aspects can vary from one society to another, relatively to the notion of “percepted risk”.

In assessing these elements, project managers have to consider both risks that can be identified by the project team (known risks) and those that cannot be anticipated in advance, such as a catastrophic event or future budget cuts. To manage a major project effectively, both types of risks must be planned for. While some risks can be avoided by changing the project plans or the way the project is performed, most will require a mitigation or risk response plan (risk acceptation and/or transfer).

2.2. Risk management at different mega-project stages

Mega-projects often last for decades in the making. It is therefore essential to consider and perform risk management at each stage of the project :

- Planning (opportunity studies)
- Design
- Construction
- Operation and maintenance (including post-crises management)

Moreover it is also essential to assure a satisfying coherence between those successive stages so that to guaranty a certain risk management continuity instead of a scheme where risks would be assumed and treated independently and in uncoordinated way by the different partners (resulting in an indefinable ownership of the joint risks).

Because of tremendous issues that are related to mega-projects, risk management processes during preparing phases are of leading importance, mostly because they allow to anticipate problems instead of just treating them.

Among the risks to be managed, those related to workers security, schedule delays, juridical risks, scope and performance creep, political and public expectations and perceptions, financial, architectural and financial risks have been recognized to be the most critical.

Some guidelines and practical tools are described and detailed below, for risks consideration, evaluation and treatment at each stage of the project.

1.1.1 *During the planning phase*

1- Define the mega-project principal characteristics (dimensions, number of lanes, cost…) and context (social aspects, owner responsibilities, environment issues, adjacent facilities, role in crisis and emergency situations). The question of the structure durability must also be raised during this first phase because it conditions the long term financial opportunity of the project, its maintenance costs as well as the different risks occurrence probabilities during its expected service life.

2- Identify and estimate (quantify) local hazards according to existing codes (national hazard mapping) and/or site investigations and expertise (seismicity, floods, soil conditions…);

3- Define objectives of performance (extreme events resistance, durability, reliability) in accordance with design codes and owner strategic choices;

<u>Note:</u> Objectives of performance are generally defined within a so-called risk matrix, the most usual form of it is presented below:

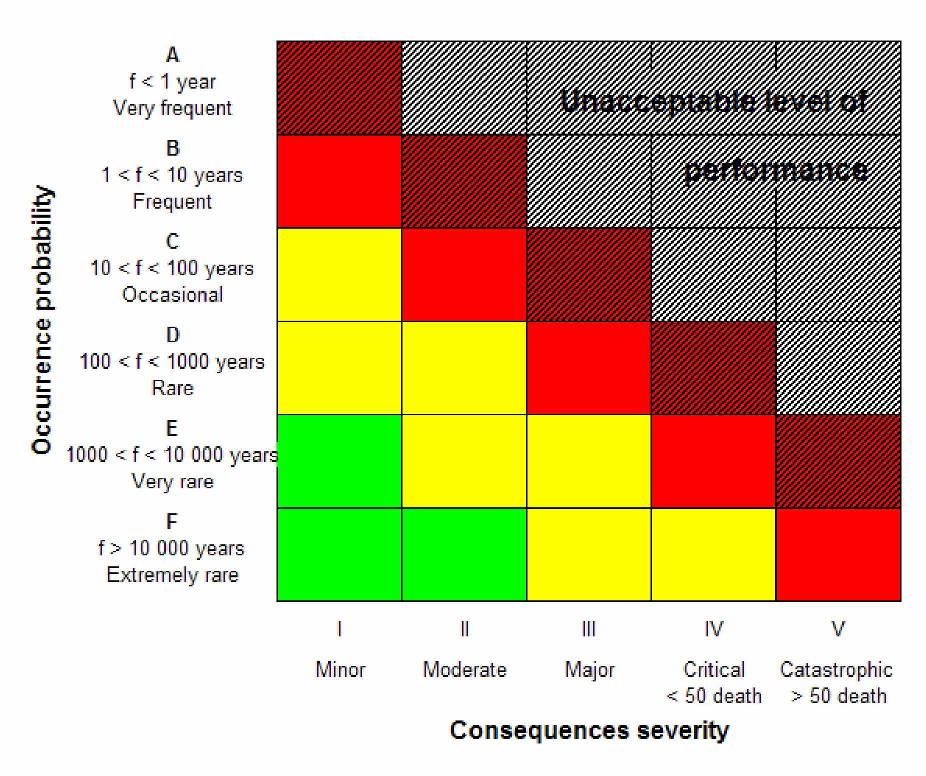

Figure 2: Example of risk matrix

In this risk matrix, green, yellow and red diagonals typically correspond to different importance classes of the structures, defined on the basis of such considerations as cost, carried traffic, strategic importance in terms of crisis management and predicted operation life. By nature, mega-project will usually state in highest importance class (green diagonal), which is the most challenging one.

One will note that the evaluation of severity levels (minor, moderate, major, critical) associated with the consequences of a given event can differ from countries and societies to others. They can be precised based on several criteria such as media coverage (local, national, worldwide), structural damages and repair cost, number of death and injuries and gravity of injuries (for road users, employees and third party), impact on environment and geographical and time spreading of this impact, time to re-establish a normal situation, level of owner responsibility engaged (financial, civil or penal responsibility), etc.

1.1.2 *During the design phase*

4- Evaluate and prioritize the risks on the structure, if needed by completing the first site investigations made (impact studies, occurrence probabilities, risk perception and acceptance by society);

5- Define the best design of the structure (bearing positioning, choice of materials and geometry, construction method) in order to reduce the risk occurrence on the structure by reducing its exposure and/or vulnerability;

Note: Steps 4 and 5 above can be gathered in one single risk identification and analysis table. This table enables, after having defined a priority coefficient for each identified risk, to compare sensitivities (vulnerability grades or indices) of different design solutions for the future mega-project:

Considered risk		Priority coefficient	Design 1	Design 2	Design 3
Naturals	Landslides	0	++	++	++
	Floods	1	++	+	++
	Earthquakes	2	+	++	- -
	Rock falling	0	++	++	++
	Wind storm / Hurricane	5	++	-	++
	Forest fires	0	- -	- -	++
Man-mades	Trafic accident	4	+	+	+
	Overloading	1	+	++	++
	Ship collision	0	-	++	++
	Airplane crash	2	- -	-	- -
	Transport of dangerous goods	3	+	+	+
	Vandalism	3	++	-	++
	Terrorism	3	-	- -	-
	Fire	3	-	-	++
Technical	Structure dimensions	3	-	-	-
	Architectural complexity	3	- -	+	- -
	Innovating degree	3	+	- -	- -
	Material choices	1	+	+	+
	Geotechnical aspects	4	-	+	+
	Construction method	4	-	+	- -
Socio-political and economical	Costs (estimated + incertainties)	5	+	-	- -
	Attractiveness	5	+	++	+
	Environmental impact	4	- -	++	+
	Landscape impact	4	- -	++	-
	Local inhabitants disturbs	3	- -	+	- -
	Srikes	2	- -	-	- -
	Work delays exceedance	5	- -	+	-
	Socio-political context	5	+	++	+
	Juridical issues	5	- -	- -	- -
		GLOBAL GRADE:	-26	25	-26

Figure 3: Example of risk analysis table

In the table above, considered risks and priority coefficients are indicative. They must be re-evaluated and explicitly justified for each new project, as well as grades given to each design solution (noted -- to ++) for each considered risk. The method still fatally exhibits some part of subjectivity and must therefore be discussed among the different partners evolved in the project. In particular, priority coefficients must take into account the hazards level on site, in terms of impact and occurrence, but also the perception and acceptance of these hazards by road users and society. It is well known for instance that traffic accidents related risks, even lethal, are generally better accepted by road users than by rail users…As a consequence, major risks to be considered in the case of a train collision generally concern train passengers security. Consequences can be very dramatic and in this field, most European and international codes propose methodologies aimed at evaluating and reducing risks related to the number of deaths. This strategy can for instance lead to design bridges column so that they could break without the bridge to collapse in front of a derailed train.

6- Calculate the structure according to existing codes and engineers considerations (state-of-the-art) in order to reduce the risk consequences on the structure; Depending on the expected guaranteed service life of the structure, measures aiming at increasing its durability, within the material and equipment choices will have to be taken so that to anticipate on future pathologies and facilitate structural inspections and maintenance works (steel reinforcement protection in concrete structures for instance).

7- List the prevention measures against risks and major disruptions in the operational phase and compare the risks with the outlined wished and/or required acceptance criteria in order to take adapted reducing measures (measurement of eventual differences with initial performance objectives);

8- Communicate on the risk management procedure and the objectives of performances required for the structure; This exchange with local inhabitants, their representatives and future road users, on project final objectives, strategic choices and adopted options enables project appropriation by the different parts and limits protestations and project disruption risks. The case of the Millau Viaduct developed further in the text is an excellent example of good communication practice.

It is during this design phase that main choices are taken that make the structure able to withstand to an appropriate extend events such as explosions, natural disasters, crash forces or consequences of human mistakes. Based on risks analysis and priority definitions, the basic principles for those choices are first to reduce hazards, then to minimize localized default consequences and finally to prevent collapse without any visible announcing damage.

The project must be looked at in terms of competences and carefulness, referring to the most actual state-of-the-art, knowledge and good practices. Reliability levels should be defined considering:

- risks towards material or immaterial goods and persons,
- prevention and its economical aspects,
- level of acceptance of the society for the considered sort of risk. This essential societal parameter can differ from a country to another, sometimes from a given region to another.

Reliability classes can be defined, that take into account consequences of disorders or bad behavior in terms of human losses, economical, social or environmental consequences and for differents types of structures.

Choices related to risks management can lead specific measures or local equipments (security barriers for bridges, fume extractors in tunnels, special paintings against corrosion, crash protections for bridge columns…). They can also modify the architectural and global design of the structure (reducing of the number of columns in case of a bridge exposed to ship or truck collisions, constitutive material, construction method, choice of a strong or slender type of structure, etc…) in agreement and under the responsibility of the owner of the project. One can thus see that in the field of mega-projects, initial technical choices and therefore global costs can be imposed by considerations simply related to security. Those choices can and should be recalibrated if alternative solutions lead to better guaranteed performances [3].

1.1.3 *During the construction phase*

9- Plan and respect some quality and security procedures in order to guaranty a good monitoring control of works and their impact, in particular during the most critical phases;

10- Plan adapted control procedures to be executed by qualified independent organisms;

11- Always prioritize safety, working environment and environment along with Time-Budget-Function / Quality;

12- Carry on communication with local inhabitants, their representatives and future road users, on project final objectives, technical choices, construction method, eventual disturbance;

13- Test the structure reliability under service and extreme or accidental loading before service opening (computer simulations validations by reduced scaled model testing, full scale on-site testing, fire tests in tunnels…);

14- Anticipate on crisis management (accessibility, moveable barriers, phone cabs, equipment stocking for repair, crisis and intervention planning, monitoring center…);

1.1.4 *During operation phase*

In normal situation…

15- Instrument and record the structure response within the service state (traffic load, wind, earthquakes…) and eventually recalibrate the computer models;

16- Inspect regularly the health of structure, materials and specific devices;

In post-crisis situation…

17- Inspect and evaluate residual resisting capacity (and eventually repair) the structure;

18- Communicate and inform every concerned identity (police, ambulances, civil security services, drivers…);

19- Eventual feed back to hazard maps, local risk characterization and design codes and practices;

1.1.5 *General prescriptions and management aspects*

Beyond recommendations specific to each stage of the project, it is very essential to plan some transversal global measures in order to guaranty a good risk management all along the project life and an efficient transition between its different phases. Among the most essential, one will note the followings:

- Decide a general plan for the project's Risk Management;
- Have a coordinator dedicated to Risk Management in the management;
- Make the best qualified to deal with the risk undertake it
- At the end of each stage, deliver the project's top 10 prioritized risks to the next phase with suggestions for action;
- State demands in the contract for the contractor's own Risk Management;
- Keep the analysis up to date.

Several risk management tools are available and were developed for instance in the USA in order to help the manager in his task [1]:

- the project management plan that must define the roadmap in terms of scope, cost, schedule, quality and responsibilities ;
- the financial plan and annual updates which the role is to establish a periodic financial evaluation of the operation ;
- the independent cost estimate verification that provides an external unbiased evaluation of the financial situation of the project in regards with forecast difficulties and conjuncture ;

- monthly reports on status ;
- project indicators, eventually based on audits, that must reflect tend lines in terms of costs, production rates, schedule, quality and safety [3].

Prescriptions listed above should be considered as some sort of ideal scheme, an objective to achieve. In fact, Risk Management in most countries has not yet reached a level where it is specifically and formally codified and standardized. However, post-analysis of successful mega-projects, included in those countries, clearly demonstrates that particular processes that were carried out at each phase of planning, design, construction and operation perfectly fit to this pre-established scheme. Design codes, state of the art, good practices, engineers good sense, experiences feed back, project organizational and quality procedures certainly enable, all together, to explain this success.

On the opposite, unlucky experiences (catastrophic work accidents, operation or financial disasters) almost always correspond to a missing link within the risk management chain. In these situations, risks were managed indirectly through the engineering decisions made during the project development. Unintentionally, risks have often been divided between the mega-project parties. Each party then focused on the risk of its primary interest which often results in an indefinable ownership of the joint risks. However, the complexity should not be a surprise to the experienced planner as the occurrence of a certain number of unplanned events is the norm rather than the exception in mega-projects.

We therefore strongly encourage responsible partners involved in mega-projects (owners, designers, constructing companies, administrations…) to adopt, formalize and systematize an integrated risk management procedure, so that to consolidate existing intuitive good practices or to prevent any eventual risky situation, the consequences of which can lead to a catastrophy. This action involves defining risk ownership and assigned responsibilities, identifying and describing risk, developing response strategies and specific actions: symptoms-warning, fallback and time/cost contingency reserves that provide risk tolerance for risk owners. Some countries like the USA, Canada, Australia, New-Zealand and Denmark

Some countries like the USA [4], Canada, Australia, New-Zealand and Denmark [5] have already made the choice of an integrated risk management for mega-projects. Results show that applying a systematic risk management in various forms to qualify decisions and to significantly improve engineer's decisions, helps to clearly identify potential problems such that appropriate risk reduction initiatives can be implemented in time. This proactive approach to identifying risks and planning for how best to avoid or mitigate those risks reap major benefits. In particular, It allows, by ensuring successful project completion within budget, to build vital new infrastructures, typically high profile and sometimes controversial, while increasing public trust and confidence. Moreover, by evaluating and communicating uncertainties in project costs, a higher quality, more reliable estimate is produced, resulting in smoother and more realistic project schedules.

3. THE EXAMPLE OF THE MILLAU VIADUCT

The Millau Viaduct [6] [7] [8] [9] was built to open a new link between Paris and South of france, and more generally Northern Europe and Spain. Its construction ended en December 2004 after a very short construction period of 38 months. This structure of exceptional dimensions is easily identifiable by its 2460 meters total length and above all by its world record height (245 meters for P2 pier).

Photo 1: General view of the Millau Viaduct at the end of its construction

Risks related to technical aspects, especially stability under strong wind conditions and difficulties resulting from building a road infrastructure at such a height played a critical role in the design choices of this exceptionnal mega-project.

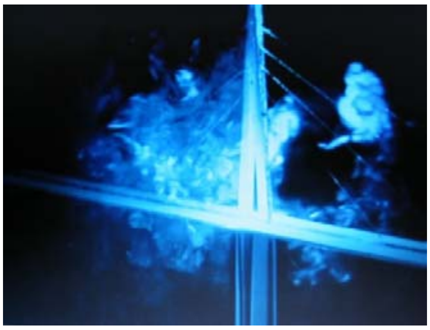

Photo 2 and Photo 3: Wind tunnel tests and pier P2 erection

Thus, after a certain number of preliminar studies made by the French State technical services, it was finally decided to set a very unusual design process consisting in an international architectural/engineering competition, and to pass a 75 years concession contract with a private company for the construction and operation of the new infrastructure. The chosen architectural solution corresponds to the vote of a 20 persons committee made of the French director of roads, technical experts, public finance specialists and local and regional representatives. During the planning and construction phases a great concern was given to environment aspects, and permanent communication campaigns enabled to explain project issues, design choices, to describe mitigation measures and make road users and local inhabitants accept and appropriate this new infrastructure. The overall great Millau Viaduct mega-project from preliminary studies to construction was deeply influenced by considerations related to risk analysis. During the operation phase, most of those risks, particularly foundation technical risks, bad-ageing risk and risks related to users security, are submitted to specific control and monitoring: deformation measurement, cable-stayed vibration control, corrosion control, ice detectors installed in the pavement structure, anemometers, video surveillance... Even more than the technical risks, financial risks and social/political aspects seemed to be very critical for the completion of this mega-project.

Photo 4: Communication campaign around the project

Finally 16 years of preparation and political processes, what represents 2 President periods and 7 Ministries of Public Works and Transportations, were necessary to complete this mega-project. The total cost is 394 Millions Euros, including viaduct construction, toll barrier, studies, financial and general fees.

4. CONCLUSION

Often decades in the making, major projects demand a complex balancing of such factors as budget, planning and design, right-of-way, construction management, environmental impacts, future operations and maintenance, and public relations.

Because of strong economic and social impact, mega-projects are often already, probably more than other more regular structures, subjected to special care and considerations relative to the risks they are exposed to, from their construction to operation phase.

However, those considerations are most of the time applied in a very intuitive unorganized and not codified way. In future, as risk management tends to become an increasing worldwide concern matter, those processes will have to become better formalized and systematized. This evolution will certainly contribute to reinforce existing good practices, to constitute an effective database and to avoid unlucky situations, the consequences of which can lead to catastrophies, thus resulting in an essential tool within the decision making process. Examples where integrated risk management processes have been adopted on mega-projects tend to demonstrate that this action is extremely efficient and beneficial for balancing the multitude of necessary elements that interfere with the project completion. They also enable to minimize uncertainties, and keep projects on track by avoiding difficulties resulting from over-costs and over-delays, while maintaining public trust and confidence.

Thus, for mega-projects even more than for classical road projects, security considerations must govern initial technical choices and therefore the cost of the structure, since the very beginning phases of planification and design. Designing and building, those are actions that cannot anymore be carried out without any reference to risks analysis. Risks management becomes a science, just like material and structural analysis sciences. It is without any doubt a “technical jump”. Taking into account the consequences of an accident, as a new parameter within the design process of the structure should change not only the project nature but also its cost. But instead of the cost to pay, it will be the cost not to pay: the accidents cost [3]...

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