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Looking back to see the future:

Building Nuclear Power Plants in Europe

ABSTRACT

The so called "nuclear renaissance" in Europe is promulgated by the execution of two large engineering projects involving the construction of two European Pressurized Reactors (EPRs) in Flamanville, France and Olkiluoto in Finland. As both projects have faced budget over-runs and delays, this paper analyses their governance and history to derive lessons useful for the construction of successive projects. Analysis indicates that the reasons for these poor outcomes are: overoptimistic estimations, First Of A Kind (FOAK) issues and undervaluation of regulation requirements. These pitfalls have the potential to impact on many other engineering construction projects and highlight fruitful areas of further research into project performance.

Keywords: large engineering project, nuclear power plants, cost escalation, delay, optimism bias

1 Introduction

In recent years the growing and renewed interest in the exploitation of atomic energy has been driven mainly by the escalation of fossil fuel prices and the global warming concerns, nuclear energy being virtually free from CO2 and greenhouse gas emissions. These imperatives have led to the construction of new Nuclear Power Plants (NPPs) and to the planning of other several hundred others, especially in China, Russia and developing countries, to assist in fulfilling the future global energy needs.

Against this background, cost escalations and delays in the two nuclear reactors under construction in Europe by Areva (an organization involved in the construction of NNPs in Flamanville and Olkiluoto) could dramatically affect the customer (i.e. the utility) profitability and increase the risk premium required by the investors. Unfortunately, these projects are not an exception: cost escalation is common also in a variety of engineering and construction projects. The aim of the investigation reported in this paper is to explore the performance problems of nuclear "new build" projects especially with respect to cost and schedule overruns through a case-based approach. The results of the analysis will be used to posit themes for consideration in the execution of other large projects, in particular nuclear reactors or projects subjected to high degree of regulation.

This paper begins with a review of relevant literature pertaining to project governance and forecasting in large engineering construction projects in order to understand current theoretical rationale for cost escalations and delays affecting this class of projects. After explaining the research methodology, the paper presents cases of the two EPR reactors under construction in Olkiluoto and Flamanville. For each NPP, it delineates the main players involved in governance of the project and the linkages among them, an historical project timeline and the regulatory environment. The paper then identifies common themes pertaining to project performance across the projects and concludes by relating these issues to the wider engineering construction environment and potential new areas of fruitful research endeavour.

2 Literature review

The literature review focuses on the two main areas of endeavour: (1) projects' governance and (2) cost and time forecasting in megaprojects. These two areas are selected because of their documented provenance in impacting upon large engineering project:

- "Project governance" is a substantive differential element in the project articulation. Both the projects are based on the same technology (the EPR reactor) but are carried out by different stakeholders with very different linkages among them.
- "Cost and time forecasting" has been identified as extremely problematic on these types of projects.

2.1 Governance in projects

Several articles have discussed governance in a project context. Reve and Levitt (1984) described trilateral governance arrangements involving a client, a consultant, and a contractor in engineering projects and highlighted different types of relationships among players participating in large projects. Turner and Simister (2001) have discussed how risk and uncertainty affect the choice of contract type in projects, and have introduced a framework of four contracting approaches. Winch (2006) has further discussed the organization of a large project involving multiple firms as a nexus of treaties, emphasizing the importance of viewing large projects as temporary organizations involving several players interconnected via inter-organizational relationships. Florical and Miller (2001) introduced the concept of governability, referring to a group of properties enabling a project to react to unexpected events occurring during its life cycle. Bettis and Hitt (1995) further develop the concept of governability including the notion of flexibility. Furthermore, the organizational structure of a project with the use of contractors, the shaping of the project, the project's institutional framework and the capacity of self-regulation are essential features of governance (Miller and Lessard (2001a, 2001b), Miller (2006)). Winch (2001) has developed a conceptual framework for understanding project governance across the project life cycle and argued that the greatest difference between traditional subcontracting and quasi-firms relates to transfer and sharing of risk between main contractor and subcontractors. Miller and Hobbs (2005) have presented a framework for understanding governance in large complex projects and emphasized the dynamic, even unexpected nature of governance in large complex projects. Turner and Keegan (2001) have discussed governance structures adopted by successful project-based organizations and argued that the governance structure of the project should take into account whether few large projects, or many small projects are undertaken, and whether projects are undertaken by a few, large dominant clients or by many small clients. In addition, Turner and Keegan (2001) introduced the role of a broker and the role of a steward to support efficient and effective governance of projects within a firm's organization. Müller (2009) has discussed governance within a firm's organization by suggesting a governance model linking governance at different project-related levels (e.g. project management, program management, strategic management).

2.2 Cost and time forecasting in Large Construction Projects

Large construction projects are notoriously characterized by enormous difficulties in time and cost forecasting. In this area, Flyvbjerg is probably the widely recognised researcher (see for example Flyvbjerg (2006a, 2007)). His studies are based on a large sample of infrastructure projects including 258 major projects completed over the past 70 years, in 20 different countries, for a total value of 90 billion dollars. Flyvbjerg uses this database showing how the availability and reliability of data on large projects affects the estimation. According to Flyvbjerg, Bruzelius and Rothengatter (2003) projects with reliable data can be managed better than average, achieving better results. Moreover he tries to quantify the accuracy of the estimation of demand for rail and road projects. By analysing a sample of 183 road projects and 25 rail projects, he discovers that the actual traffic of passengers in a rail project is overestimated by 105.6%. For road projects, however, the actual traffic of vehicles is 9.5% higher than estimated. Flybjerg, Holm and Buhl (2006) note that the inaccuracy of estimation is not specific to a given country and it is constant over 30 years.

Beside roads and railways, the nuclear sector represents one of the most interesting engineering construction fields to apply these approaches because of its social and economic dimensions. In particular, there is a difference between nuclear and other infrastructure projects: most of the design mistakes within nuclear design, if not discovered in due time, can only be corrected by mammoth efforts and have huge impact on the delivery time. In large engineering construction projects (in particular in the nuclear infrastructure) the impact of even relatively small problems could become catastrophic for the companies involved and for those countries that invest too high a level of resources (human and financial) in their execution. For instance, in the N4 reactors (the precursors of EPR), construction began between 1984 and 1991, but full commercial operation did not begin until between 2000 and 2002 because of thermal fatigue flaws in the heat removal system requiring the redesign and replacement of parts in each N4 power station (Grubler (2010)).

Quinet (1998) and Trujillo, Quinet and Estache (2002) shows that the main origin of estimation problems is not in the inadequacy of the methodologies, but often lies in in common strategic data manipulation due to the normal optimism that strongly characterizes projects at their conceptual phase (Wachs (1990), Lovallo and Kahneman (2003)).

In order to cope with these problems in megaprojects, Flyvberg proposes the reference class forecasting approach that involves the following three steps:

- Identifying a reference class of past, similar projects.
- Establishing a probability distribution for the selected reference class for the parameter that is being forecasted.
- Comparing the specific project with the reference class distribution in order to establish the most likely outcome for the specific project.

In order to further investigate the issues raised by the literature review, the following section will present two case studies: Olkiluoto 3 (OL3) and Flamanville 3 (FL3). The section also presents the methodology used to build and analyse these cases.

3 Research Methodology and Data Collection

The nuclear sector is identified as a very specific field characterized by a high level of technological and organizational complexity due principally to the levels of safety to be reached and assured during the overall life cycle of the plant (design, construction exercise and dismantling) (Ross and Staw (1993), Ruuska *et al.* (2009)). The case study methodology presented in this paper has been informed by two main sources: Yin (2003) and Flyvbjerg (2006b). Yin (2003) shows how case studies are a valuable tool to the answer to questions as "what", "how often" and "when". Flyvbjerg (2006b) identifies appropriate situations in which to apply the case study approach and how to answer to the recurring critiques towards this method.

3.1 Case selection criteria

According to www.world-nuclear.org, as of October 2011, there are 63 nuclear reactors under construction in the world. Most of them are in China (27), Russia (10) and India (6). As far as Europe and the USA are concerned, the distribution is a follows: Finland (1), France (1), Slovakia (2) and USA (1). The construction of the reactors in Slovakia (Mochovce 3&4) and the USA (Watts Bar 2) started in the 80s, but due to poor financial control, lack of funds and political reasons they were temporarily abandoned and only restarted construction a few years ago. Therefore the only "new" reactors in the EU and the USA are the EPR under construction in Finland and France. The investigation of these two case studies provides an appropriate representation of future construction in EU and USA especially since nuclear sites are contextually specific projects. Moreover, from the cross-case research perspective, this is a fortunate situation. As the cases share the same technology (EPR reactors), the differences in project performances is more likely to lie in the governance and other managerial aspects of the projects.

3.2 Data gathering and case analysis framework

The construction of a nuclear reactor is a project that for various reasons (public acceptability, political discussions, national economy implications etc.) raises a great deal of interest in politicians, the media and the general population. Therefore, when compared to other projects with a similar budget (e.g. building a new large car manufacturing plant or a submarine pipe for natural gas) many more documents are publically available. In particular there are three groupings of documents.

1. The official documents from national control authorities. Because of the intrinsic hazard of a nuclear plant they are controlled by national regulatory authorities (e.g. in France and Finland ASN and TVO respectively). These regulatory authorities periodically provide official reports that they make freely available from their web-sites.
2. Documents produced by reactors vendors and suppliers. On their web sites, these organisations frequently have specific and detailed sections dealing with projects. In these sections, organisations provide an overall summary of the project as well as progress updates from both a technical and management perspective. They usually also provide revised forecasts for the projects in terms of cost and time
3. Documents produced by Utility Clients Teollisuuden Voima Oyj (TVO) and Électricité De France (EDF) are the utilities (Finland and France respectively) that will own and operate the power plants. They provide official statements about the projects and their progress in their own websites.

These three sources accounts for most of the data used to create the cases for the two projects under review. This information is public and official. Unlike individual interview data, these data are accessible to everyone and are sanctioned as reflecting the point of view of an entire organisation (and not a single person) Beside these official data sources, we considered also information provided by media (newspaper, websites etc.). When an incident or problem was repeatedly reported in several sources, a comparison was made of how the reporting differed in the sources.

In relation to the validity and reliability of this research, the use of this type of rich public evidence, archival records and documentation, has both advantages and disadvantages. According to Yin (1989, p. 17) archival analysis in case study research can be used to answer such questions as what, how often and when. However, typically archival and documentary data are completed with other types of evidence such as interviews and statements for the purposes of triangulation. Hence, our sources of evidence may potentially affect the validity of our findings (Yin (1989)). However, one advantage of the use of this kind of rich and public data is the fact that we can openly discuss the data and our findings in the analysis, by posing the data and the findings for public critique. Such public critique may help to test the correctness of the content of our analysis. More specifically, the data concerning OL3 consists of:

- Public information provided in the Internet sites of the key players: AREVA, TVO, STUK (Radiation and Nuclear

Safety Authority, Finland) and Ministry of Employment and the Economy and broadcasted TV documents and news broadcasts about the plant.

- The extensive and in-depth investigation report about the OL3 Project's challenges published by STUK in June 2006 (STUK Investigation report 1/06: Management of safety requirements in subcontracting during the OL3 nuclear power plant construction phase).
- The most important articles published in the Finnish leading financial periodicals and newspapers about OL3 between the years 2001 and 2011 (these periodicals and newspapers include: Kauppalehti, Talouselämä, Tekniikka ja Talous, and Helsingin Sanomat).
- The most important articles published in electronic periodicals and newspapers in French about OL3 between the years 2003 and 2011 (these periodicals and newspapers include: Le Monde, Le Figaro, Le Canard Enchaîné, Les Echos, L’Express, Le Nouvel Observateur, Le Point, and Challenges).

Our research data of FL3 consists of:

- Public information provided in the Internet sites of the key players: AREVA, EDF, Bouygues, ALSTOM and ASN (the French national authority in radiation and nuclear safety) and news broadcasts about the plant.
- The most important articles published in electronic periodicals and newspapers in French about FL3 between the years 2003 and 2009 (these periodicals and newspapers include: Le Monde, Le Figaro, Le Canard Enchaîné, Les Echos, L'Express, Le Nouvel Observateur, Le Point, and Challenges).
- Information provided by specialized web sites: www.world-nuclear-news.org, www.world-nuclear.org, www.francenuc.org, www.french-nuclear-safety.fr, thomsonreuters.com, www.reuters.com, www.cbc.ca, www.telegraph.co.uk, www.guardian.co.uk, www.spiegel.de/international, www.mobile.france24.com, www.french-nuclear-safety.fr, www.bmu.de, www.energy.edf.com, www.unistarnuclear.com, and www.bouygues-construction.com.

4 Research Framework

The research framework is structured in three main phases and is illustrated in Figure 1.

Phase 1 – Atlas Coding

The analysis of the collated dataset has been assisted by the use of the qualitative data analysis program ATLAS.ti (version 5.2). The primary rationale for using ATLAS.ti was to facilitate the management of large amount of research data. The coding in ATLAS.ti assisted in organizing the data presented in section 3.2 in homogenous clusters of data concerning a range of attributes of the projects. (see Figure 1).

Phase 2 – Cases construction

Cases are constructed by assembling the clusters of data created in Phase1 into a common template (which, for each case, comprised:

- The regulatory framework
- Key Actors and their relationships
- A "time-line" history of events

Phase 3 – Cross case comparison

The template acted as a framework to make cross-case comparisons. These comparisons identified where similar case configurations had led to similar performance issues. The similarities were then grouped into emergent 'themes' that related project governance and forecasting to project performance.

Insert Figure 1 here

Figure 1 Research Framework

5 The Cases

The following section presents the cases the first in Finland (OL3), the second in France (FL3), that were the focus of this investigation. Both cases use the EPR a 1650 MWe Pressurized Water Reactor. This is a first-of-a-kind (FOAK) technology.

5.1 Olkiluoto 3

OL3 is the fifth nuclear power plant built in Finland. TVO, the utility owner has selected AREVA NP to deliver the entire power plant on a lump-sum turnkey delivery basis. As architect engineering (A/E) and main contractor AREVA NP is responsible for organizing both the engineering and the construction of the entire plant

5.1.1 Key actors and their relationships

AREVA NP: Is the A/E, reactors vendor and main contractor for the nuclear island. It is owned by AREVA SA, a French industrial group 90% of which is owned by the French State (including the shares owned by the CEA). ARREVA SA is divided into three main divisions which cover all the aspects of generating electricity with nuclear technology. Areva NP is one of these divisions. Originally, Areva NP was a joint venture of AREVA SA and Siemens. In January 2009, Siemens closed the shareholders agreement for the joint venture and sold its 34% stake to Areva, the majority shareholder. An independent expert appointed by Siemens AG and Areva SA has determined the value of Siemens' share in the nuclear power joint venture Areva NP S.A.S. at EUR 1.62 billion(Nei (2011)).

BOUYGUES: is a French construction company. It is the main subcontractor of AREVA NP providing the construction of civil works in OL3 (and FL3).

CEA (Commissariat à l'Energie Atomique et aux énergies alternatives - Atomic and Alternative Energies Commission): is a French "state owned establishment related to industrial and commercial activities" whose mission is to develop all applications of nuclear power, both civilian and military. It owns 79% of AREVA SA shares.

FRENCH STATE: Owns the CEA and 85% of EDF SIEMENS: is a German engineering conglomerate in charge of designing and building the Conventional Island (which include the turbines).

STUK (Radiation and Nuclear Safety Authority) operating under the Finnish Ministry of Social Affairs and Health is responsible for the supervision of nuclear safety and the use of radiation. It is a regulatory authority, research centre and expertise organization, whose mission is to protect people, society, the environment and future generations from the harmful effects of radiation.

TVO is a public limited company producing electricity for its shareholders at cost price. The TVO largest owners are Fortum Power and Heat and Pohjolan Voima, with a combined ownership of over 80%. TVO already owns the two NPPs operating in OL3. It is the client of the Areva – Siemens consortium. It will own and operate the OL3 reactor.

Insert Figure 2 here

Figure 2 Stakeholders in OL3 project. Owner and A/E highlighted

5.1.2 History of event within the project

OL3 marked the return of Western Europe to nuclear energy after a period of twenty years since the construction of the last nuclear reactor. In 2003 the Finnish utility TVO and the consortium Areva NP & Siemens AG signed a 3 billion Euro turn-key contract for this reactor with an expected delivery in 2009. The present situation is quite different: the cost estimate has escalated to 5,3 billion of euros (2011e), and the unit is scheduled to be ready for regular electricity production in August 2014(2011d). . The cost overrun is considerable, and Areva NP has considered writing down 2.7 billion of Euros of the 3.3 billion of Euros project in its accounts (World-Nuclear (2011)). In the first half of 2008, TVO submitted a claim to Areva and Siemens for compensation for "losses and costs incurred due to the delay" in completing the construction project. TVO had also rejected a claim presented to it by Areva and Siemens contesting that it had been much slower than agreed in processing and passing on technical documents to STUK. The Areva-Siemens consortium has filed a request for arbitration with the International Chamber of Commerce ((World nuclear news (2010))

STUK performs periodical audits to carefully check the compliance of in-site/off-site activities and documentation according to the rigorous Finnish nuclear regulations. In the 2006 STUK issued a long report highlighting the deficiencies in the project management and quality management of OL3 project (e.g. the concrete of the base slab was poured twice due to severe problems concerning the non-compliance with the nuclear standards). Special requirements of nuclear power plant building were not emphasized in the call for tenders. Other deficiencies concern the “poor quality documentation”, “construction inspection”, “quality management”, and “welding”. Deficiencies, reworks and general mistakes have postponed the completion to 2014 and almost doubled the cost.

A complex multi-firm network embodies various roles and responsibilities. Due to the turnkey contract, TVO delegated delivery responsibility to AREVA NP. AREVA NP as the main contractor further delegated certain responsibilities to its own suppliers. The turnkey contract reduced TVO's control of the subcontractors including the ability to monitor safety issues.

During the building of the plant this lack of control emerged as an issue. For example, conflict existed due to unclear responsibilities in defining the composition of the concrete. Furthermore, both AREVA and TVO experienced challenges that were related to their roles in the project. For example, STUK identified deficiencies in TVO's capabilities to act in the role of a buyer (STUK Investigation report 1/06).

These difficulties have led to a number of delasy in construction.According to Vehmas (2010), construction started in 2005 and the commercial operation was expected in the first half of 2009, but there were continuous revisions of the commercial operation date, as showed below:

11.07.2006: OL3 into commercial operation in 2010

28.12.2007: AREVA-Siemens estimate OL3 to start operation in summer 2011

17.10.2008: Start-up of OL3 may be postponed until 2012

13.01.2009: AREVA-Siemens now estimates OL3 will be completed in summer of 2012

15.10.2009: Start-up of OL3 nuclear power plant may be postponed further

07.06.2010: OL 3 will be in electricity production in 2013

21.12.2011 AREVA-Siemens Consortium, which is constructing the OL3 nuclear power plant unit on a fixed-price turn-key contract, has informed TVO that the unit is scheduled to be ready for regular electricity production in August 2014.

5.1.3 The regulatory framework

The Finnish regulatory framework for nuclear power plant construction is encapsulated using five attributes:

Legal framework: "prescriptive based": the law establishes the general principles and the detailed provisions are appointed in the standards and guidelines.

Main players: the main decisions on whether or not to grant site licences are the responsibility of the government and the regulatory body (STUK) for the technical aspects related to safety.

Steps and related time: There are two main steps: obtaining a construction License (which takes 2-3 years) and obtaining the operating licence (issued in parallel with the construction).

Public Involvement: the public hearings are instigated with regard to the decision-in-principle and only involve the stakeholders in the vicinity of the site.

Nuclear program: the strategic development of nuclear program is led by the government, who operates as energy planner, and the utilities.

5.2 Flamanville 3

In mid-2004 the board of EdF decided in principle to build the first demonstration unit of an expected series of Areva EPRs. This decision was confirmed by the EdF board in May 2006, after a public debate, when it approved construction of the EPR unit at Flamanville, Normandy, alongside two existing 1300 MWe units. The decision was seen as an essential step in replacing aging EDF's reactors. The construction of FL3 is the first NPP built in France since the N4 program.

5.2.1 Key actors and their relationship

Beside the project players already presented in 5.1.1 other are involved in the FL3 project:

ALSTOM: is the largest French conglomerate concerned with mechanical engineering, working in the railway and electricity production sectors. The company has been awarded a 350 million Euro contract for engineering, procurement, construction and commissioning of the conventional island for the FL3 reactor (steam turbine, generator, condenser, moisture separator heater and auxiliary equipment). Each EDF reactor has a conventional island provided by Alstom.

ASN (Autorité de Sûreté Nucléaire): is the French regulatory authority responsible for ensuring nuclear safety and radiation protection, in order to protect workers, the public and the environment from risks associated with nuclear activities.

BOUYGUES: In FL3, Bouygues is responsible for the civil works (engineering and construction) of a value of 300 million euros. On 31 March 2009, Bouygues owned approximately 30% of Alstom shares.

EDF (Électricité de France) is the biggest French utility and the French Government owns 85% of its shares. It operates 59 nuclear reactors with a total capacity of over 63 GWe. EDF is the A/E for the construction of the reactor FL3 with responsibility for project management, definition of standard technical reference, allocation, management and supervision of contracts and interfaces with the security regulatory body (ASN). EDF has held this role in the design and construction of all French reactors currently in operation.

ENEL is the largest Italian utility, the Italian state owns directly and indirectly 30% of its share. ENEL participates in the construction of the EPR in FL3 owning a 12.5% (investment of approximately 450 million of Euros), with the option to invest in the next five EPR for a share of up to 12.5%. ENEL engineering staff, distributed across EDF, are participating in the design and construction of this power plant

Insert Figure 3 here

Figure 3 Stakeholders in FL3 project: Since the authors are Italian focused on the role of Italian firms. Owner and A/E highlighted

5.2.2 History of event within the project

FL3 is a "made in France" reactor in which the French State is the main player since it controls the project delivery chain: directly through the regulatory authority (ASN), through its ownership of the client (EDF), and through its ownership of the prime contractor (AREVA SA/NP). This approach is similar to the one used in the 70s and 80s (Grubler, (2010)). The Government aims to deliver standardization criteria to maximize the economies of learning (and scale) for future investments. A regular bidding phase (similar to OL3) did not take place in FL3, since EDF selected AREVA NP for the construction of this reactor directly as the French State owned both firms. Although ASN is part of the French State, it prioritizes safety over the interests of EDF and AREVA and acts independently and transparently. This has been made evident by the many decisions made by ASN. For example, it ordered the suspension of the works for the reactor base slab for one month in May 2008 submitting a corrective action plan, followed by the detection of several deviations in concrete structural work early in 2008

EDF started in 2006 to build the first EPR reactor at Flamanville. The design principles retained for EPR are based on an evolutionary concept relying on mastered technologies supported by the feedback gained in France and Germany and from the results of constructing the Finland OL3 unit. EDF is both operator and A/E of this power plant, working in close cooperation with the subcontractors and ENEL. This arrangement between EDF and companies forming part of the industrial sector has previously been a successful one for all the French nuclear fleet. However, this has not been the case for FL3. FL3 was expected to cost approximately. 3.3 billion Euro (2005) and to be connected in 2012. In July 2011 the new official forecasts were a cost of 6 billion euros, (about 90% over budget,) and commercial operations scheduled for 2016 (EDF, (2011)).

In the 2011 EDF in a press release (reported in appendix A) which identified the main reasons for the delay and budget overrun and the corrective actions required. These were given as FOAK issues and the consequences of the accident in Fukushima.

5.2.3 The regulatory framework

The French regulatory framework for nuclear power plant construction is encapsulated using five attributes:

Legal framework: "prescriptive based" and fragmented in many different documents issued by different subjects.

Main actors: The governance structure is fragmented. Most of the licensing decisions are issued by the system of “double checks.” The regulatory body (NSA) acts as consultant (on the technical matters) and the government takes decisions on the basis of this

Steps and related time: Construction permits and operating permits are required. (The licensing lead time is prescribed as three years but there are some examples where the period was longer)

Public: Public inquiries are coordinated by the Prefect. The Information is controlled by a chain: NSA communicates with the local information committees and the Prefect who, in turn, coordinates the information provided to the media.

Nuclear program: the strategic development of the nuclear program is led by the government. A key feature of the program is the high standardization of the reactor design to achieve economies of scale and learning.

6 Cross-case comparison

Both of these projects experienced substantive performance problems: they are both likely to be around 5 years later than planned in going into operation and they have both experienced cost escalations in the order of 80%. In order to explore the performance of these projects, this section reports on a cross-case comparison of the two cases. By examining the cases for points of similarity in the case templates, this analysis posits that the causes of failure can be grouped into two meta-themes:

1. First of a Kind (FOAK) effects in a highly regulated environment;
2. Forecast unreliability.

6.1 FOAK effects for megaprojects in a highly regulated environment

It appears an oxymoron to define the construction of both the EPR reactors using the same technology as FOAK projects. However, even if the technologies are the same (two EPR reactors), these two projects are executed by inexperienced A/Es and supply chains (who were particularly unfamiliar with the regulatory context) who experienced these projects as the first of this kind.

According to IAEA (2008), in nuclear engineering construction projects, the A/E plays a key role in determining the performance of the project especially in terms of managing project information. In the case of OL3 AREVA was, for the first time, the A/E of a nuclear construction project. In the case of FL3, it is true to say that EDF has a long history and experience as a nuclear construction project A/E as it is the A/E of all its 58 French reactors now in operation (ANS, 2011). EDF commissioned 44 GW between 1980 and 1990. The more recent of them started the commercial operation in the 2002 (even if the construction was finished in the 1999)[1]. It must be noted, however, that the EPR is a radically different technology from that used before and caused many FOAK issues even to an experienced A/E such as EDF. Furthermore, EDF was working with a new network of relationships which it had not employed before. This indicates that FOAK effects are highly contextualised.

[1] EDF worked as A/E selling it 940 MWe PWR also in China in the project Daya Bay 1&2 and Ling Ao 1&2(He 2008). EDF took part also to other projects Koeberg 1&2 (South Africa), more recently Mochovce 1&2 (Slovakia) and Ling Ao 3&4

FOAK effects are also in evidence in the supply chain in both of the cases. In FL3 and in OL3, the regulatory authorities (ASN and STUK respectively) held up construction because of the poor quality work undertaken by inexperienced contractors. For example, in OL3, the contractor responsible for laying the concrete was unfamiliar with the tight regulatory environment and thus failed to follow quality procedures and used an unapproved form of the material. The rework of this defect caused several months of delay and a cost escalation. In another instance, a failure to educate sub-contractors led to delays in the construction of the base slab and liner due to the use of an unapproved welding procedure. In the case of FL3, ASN halted construction because of problems with steel works that formed part of the foundations. ASN identified that this was due to sub-contractors' inexperience of working in a highly regulated environment with stringent quality controls.

It is interesting to speculate, given the use of the same EPR, how the FOAK effects could have been avoided. Poor performance on both projects could be deemed the logical consequence of changing the A/E (EDF instead of AREVA), the conventional island supplier (ALSTOM instead of SIEMENS) and the regulatory scenario (enforced by ASN instead of STUK). Maintaining, as far as possible, the same governance structure may have gone some way to eradicating performance problems.

6.2 Forecast unreliability

In both cases, the projects have significantly underestimated the time and the resources required to complete construction. Whilst the failure to reach targets may be due to FOAK effects that are hard to predict, Failure to set targets may also have been due to the overly optimistic nature of the target. In order to 'gauge' the realism of the targets used in FL3 and OL3, It is useful to apply reference forecasting in order to evaluate the gap between planned and actual data regarding the cost and schedule of the project. Figure 4 shows that the initial forecast for the EPR (2005) for FL3 seems have been too optimistic if compared to previous values of reactors built in France: the figure clearly shows that an increase in size increases the construction time, and the EPR is bigger than any other reactor. Moreover the EPR reactor is based on the German reactor "Konvoi" and the French reactor "N4". The decision to develop and build the N4 reactor was the most problematic of the entire French PWR program: the new reactor faced numerous technical difficulties, substantial delays, and by French standards prohibitive cost overruns. Not a single N4 reactor was exported. Focusing on these reactors, in particular Table 1 and Figure 5, it is clear that the initial forecasts were overoptimistic. The previous reference reactors were completed in about 10 years and they had been built during the “golden age” of nuclear power when the entire project delivery chain was experienced and FOAK effects were therefore minimised. The new EPRs are bigger, more complex and built by inexperienced supply chains. Nevertheless, the initial estimation forecast a 50% reduction in the schedule: both forecasts for FL3 and OL3 demonstrated an optimism bias in their forecasting (c.f. Flyvbjerg (op. cit)). So, if Figure 4 shows the historical schedule of French PWRs and FL3 forecast, Figure 5 demonstrates the rationale of the reference class forecasting. Figure 5 and Table 1 compare the historical schedule of N4 and Konvoi reactors vs. the EPR forecasts and actual values. It is clear as the actual values match the historical performance, as expected with a “reference class” forecast.

Insert Figure 4 here

Figure 4 Historical construction time of French reactors according to Grubler (2010)

Insert Figure 5 here

Figure 5 Construction time comparisons

Insert Table 1 here

Table 1 Cost and construction time according to IAEA (2011) and Grubler (2010)

7 Conclusions and Implications

The aim of the investigation reported in this paper was to explore the performance problems of nuclear "new build" projects using a case-based approach. As a result of the cross case comparison between the two cases reviewed, two potential emergent groups of explanations for the poor performances of these projects have been proposed:

- FOAK issues in terms of both the capabilities of the architect-engineer and the supply chain
- Poor forecasting leading to unrealistic targets (so that it is no surprise that the projects overran!)

These tentative findings have potential implications for the nuclear new build power plants; European engineering construction projects in general and other researchers in the field.

i) Other nuclear new build power plants

A number of issues in project performance uncovered by this investigation relate to the lack of experience of the actors in these types of projects. This suggests that the more experienced the actors in building these projects: the more likely that they are to complete these type of projects on time and to budget. This finding echoes the experiences elsewhere. Nuclear experts (Hecht (2000), Grubler (2010) and Choi *et al.* (2009)) agree in defining the (old) French and (present) South Korean programs as 'success stories.' In those countries a consistent group of organisations comprised the project delivery chain and, after the definition of a standard design, they delivered several power plants. These countries established network relationships in order to deliver a "nuclear program" (i.e. several, almost identical, reactors) rather than individually commissioned power plants. Most of the time the A/E and the subcontractors were able to deliver the reactors on time and on budget (with the exception of N4 France reactors). Contrary to this approach, David and Rothwell (1996) show that, in the USA, each reactor has its own project delivery chain and each reactor is different. According to Joskow (2006) the overall cost escalation in this context has been 300%. In large projects, especially in the nuclear field, a key strategy to achieve good performances appears to be the standardization of the project delivery supply chain and reactor design. This suggests that project performance problems in nuclear new build can be alleviated through standardisation (both in design and in construction methods.) The creation of a simplified European standard for nuclear construction could provide a first, fundamental, step in that direction. Moreover common European regulations relating to nuclear construction could be developed: nuclear safety standards common to all of Europe could allow a better standardization of the nuclear plants reducing also their capital costs and construction delays. The findings of the cross-case comparison also suggest that, for the so-called “nuclear renaissance” to take place, a capable subcontractor base must be created.

ii) European Engineering Construction projects in general

The cases highlight that, in both of the projects, the initial performance estimations were optimistic. (Construction time estimates were shorter than the duration of any other similar projects.) The cases provide evidence of the same ‘optimism bias’ that Flyvbjerg (2006a) found in road and rail megaprojects. This suggests that ‘optimism bias’ is not confined to any particular sector and that more reliable forecasts are required for engineering construction projects in general. In addition, many engineering construction projects are operating in areas where there are high degrees of regulation that are almost as onerous as nuclear safety. The experiences in OL3 e FL3 suggest that not only the A/E or (EPC) has to understand the regulation so should the client and the and the sub –contractors. Large investments in training may therefore be necessary to prevent over budget and delays due to authorities’ actions.

iii) Researchers in the field

The findings of the case-studies provide interest staging points for further investigations by construction management researchers. The impact of FOAK effects on project performance provides further evidence of the importance of knowledge management in projects in particular the issues surrounding the transfer of knowledge across projects. Although still a topic of considerable interest (as suggested by Rezgui and Miles (2011) and Robinson et. Al (2010)), the experience of these cases suggests that an even greater understanding of the role played by knowledge management in insuring project performance is imperative. The case-studies suggest that a project governance perspective may be a fruitful way in which to purse these investigations further. The presence of optimism bias in the context of these projects also is worth of further investigation. Flyvbjerg (op cit) posits that this sort of behaviour is due to stakeholders pursuing goals self-interest in initiating projects. It would be interesting to understand further the role that optimistic forecasts play in engineering construction projects.

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APPENDIX A: OFFICIAL PRESS RELISE BY EDF ABOUT THE DELAY OF FL3 (2011c)

EDF will start selling the first KWh produced by the EPR at Flamanville in 2016

EDF has decided to introduce a new approach to organisation at the Flamanville (Manche) EPR in response to recent events that have slowed down progress on the work site. As a result, the first KWh produced by the EPR will be sold by EDF in 2016.

This delay is linked to both structural and economic reasons. FL3 is the first nuclear power plant to be built in France for 15 years. It is also the first EPR.

In terms of industrial management, EDF has had to review its assessment of the extent of the work to be done, particularly in terms of civil engineering (iron reinforcements and anchor plates, much higher than initial estimates, etc.).

While considerable progress has been made in recent months (80% of the civil engineering work has been completed, a start has been made on assembling the piping and electrical equipment), there have been two serious accidents, one of which has meant that civil engineering work had to be suspended for weeks, considerably slowing down progress for the first half of 2011.

As well as this, comprehensive analyses carried out as part of the post-Fukushima safety assessment audits will be submitted to the Nuclear Safety Authority in September.

Faced with these challenges, EDF has decided to introduce a new approach to organisation with its partners, including:

- the definition of a new, more reliable industrial schedule incorporating all of these points;
- the launch of regular public “site” meetings to assess the progress of the project as well as the key advances made (positioning of the dome in 2012);
- the establishment of new practices in terms of management and supervision of the site;
- the coordination of teams and partners with, for example, the creation of the “F10 committee”, bringing together the 9 main companies working on the site;
- the consolidation of requirements in terms of safety and preparation for intervention operations.

This updated project, worth now some 6 billion euros, will give EDF valuable feedback and a tried and tested approach to organisation for future EPR reactors, particularly in the United Kingdom.

"We are faced with the demands of a major site, and we have had to put together an appropriate industrial framework for us to succeed with this ambitious project. That is what has led us to introduce a new approach to the organisation of the site today" explained Hervé Machenaud, EDF's Group Senior Executive in charge of Production and Engineering, Philippe Bonnave, Deputy CEO of Bouygues Construction.

"The success of the Flamanville EPR is a major challenge for the industrial expertise of the nuclear industry. We will continue to work together on the feedback from the first EPR sites in order to learn from it for the benefit of future construction projects around the world" announced Hervé Machenaud EDF's Group Senior Executive in charge of Production and Engineering and Claude Jaouen, Director of the Reactors and Services Unit at Areva.

TABLE 1

Type	Location	Net Capacity [MWe]	Construction Started	Connected to Electricity Grid	Commercial Operation	TOTAL Const time [years]	COST (historical value, local currency)	COST (historical value, EURO, billions)	COST at 2011 € (conservative 5% discount)
N4	Ardennes	1500	01/01/1984	30/08/1996	15/05/2000	12.7	15.8	2.41	5.01
N4	Ardennes	1500	31/12/1985	10/04/1997	29/09/2000	11.3	16.8	2.56	5.32
N4	Vienne	1495	15/10/1988	24/12/1997	29/01/2002	9.2	16.8	2.56	5.32
N4	Vienne	1495	01/04/1991	24/12/1999	23/04/2002	8.7	31.6	4.82	10.02
Konvoi	Brokdorf	1410	01/01/1976	14/10/1986	22/12/1986	10.8			
Konvoi	Philippsburg	1402	07/07/1977	17/12/1984	18/04/1985	7.5			
Konvoi	Isar	1410	15/09/1982	22/01/1988	09/04/1988	5.4			
EPR	Olkiluoto	1650	12/08/2005		01/08/2014	9	8.0		
EPR	Flamanville	1650	03/12/2007		31/12/2016	9	9.1		

Table 1 -Cost and construction time according to IAEA database (2011a) and (Grubler 2010)