The divergence between actual and estimated costs in large industrial and infrastructure projects: Is nuclear special?

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Chapter III.4. The divergence between actual and estimated costs in large industrial and infrastructure projects: Is nuclear special?

Large capital-intensive projects such as NPPs have had in recent years a poor record in delivering on budget and on time in most NEA and OECD countries. On the plus side, the nuclear industry has long been counting on the learning effects of building a series of given reactor types to bring costs down. Recently, however, researchers have questioned whether the costs for new build are increasing rather than decreasing (Grubler, 2010; Locatelli and Mancini, 2012). Assessing whether potential cost reductions from learning over the course of constructing several units are in fact outweighed by other factors such as increases in resource costs or regulatory uncertainty, is made difficult by the fact that there are relatively few projects from which to draw conclusions. Although there is a reasonable roll-out of broadly comparable generation II designs across the globe, there are substantial differences in the economic, political and regulatory environments in which plants are built. And the variations to standardised designs to allow for local regulatory conditions mean that there is limited experience in reality of building to standardised designs.

Westinghouse believes that the experience of building PWRs in Korea between 1995 and 2005 shows reductions in both costs and construction times that are consistent with estimates that series build of a standard design can obtain cost reductions of around 30%. They attribute the cost savings to standardisation and also currency stability resulting from localisation of equipment supply (Matzie, 2005).

Whether this experience can be replicated in western markets is subject to a wideranging debate. A study of the French nuclear programme, while considering it to be the most successful scaling-up of a complex, large-scale technology in the recent history of industrialised countries, examined the causes of cost escalation over the programme (Grubler, 2010: 5174-5188). Despite the favourable institutional setting of centralised decision making and regulatory stability, the cost of PWR units constructed in the mid-1990s were considerably higher than those built at the beginning of the programme two decades earlier. The study considers that several intrinsic characteristics of nuclear construction, such as their size and complexity limit the opportunities to achieve cost improvements through the classical mechanisms of standardisation, large series and repetition of experience, i.e. economies of scale production over several reactors.

Subsequent studies however pointed out that the Grubler study failed to distinguish between different series of reactors with sometimes considerable technical differences. At a recent workshop organised by the NEA, presenters both from AREVA and the French Ecole des Mines agreed that when comparing like with like, learning-by-doing and cost reductions do exist in the French nuclear industry (Jannet, 2014; Berthelemy and Escobar Rangel, 2013). When considering each technological series separately, the French nuclear programme thus achieved, according to AREVA, construction cost reductions between the first and last unit of each series that vary between 2% (CP0, 6 units) 26% (CP1, 18 units) with an average of 16% (calculations based on the widely recognised *Cour des Comptes* [2012] report).

As far as more recent experience is concerned, construction at the EPR at Taishan (China) boasts a 60% reduction in engineering hours, a 50% reduction in months of civil work, a 40% reduction in the months of manufacturing of heavy components and a 30% reduction in months of welding of primary loop when compared to the EPR at Olkiluoto 3 (Finland). EDF reported similar progress between the construction of the EPR at Flamanville (France) and the Taishan project as the pouring of the raft of the nuclear island was reduced from 4.5 months to 1 month and putting the liner cup on the base slab from 47 to 10 weeks (see also the full case study on Flamanville 3, Taishan 1 and 2 and Hinkley Point C 1 and 2 in Section III.5.1).

The reasons for these reductions lie both in technical improvement (one-batch pouring for the base slab, reduced steps for the pouring of the containment base) and organisational advances such as the reduction of management interfaces. A key question that was left unanswered is, of course, whether this impressive progress is a technological series effect or a country effect. The planned EPR at Hinkley Point (United Kingdom) is thus expected to have similar lead times but higher costs. This points towards the wider issue of how to account for learning-by-doing. Shall the series be constructed by technology (as do AREVA and EDF) country, company or even team? Research by the French Ecole des Mines for instance is based on companies and show that on average there is a 12% decrease in construction costs when moving from a FOAK reactor to a second reactor, with a FOAK premium varying between 10% and 40%. The main reasons are better co-ordinated supply chains and reduced risks of regulatory intervention. This gives a premium to less diversified nuclear fleets and the authors have calculated that a 10% decrease in the logarithmic HHI index of diversification will reduce costs by approximately 22%. The relevant metric might even be the team rather than the company.

The IAEA Secretariat thus pointed out that the CANDU project at Quishan, for instance, one of the few major nuclear projects to be completed *ahead* of schedule, was built by a team that had immediately preceding experience with two other CANDU reactors (Moore, 2014). This stability of the teams was also a factor in the overall very satisfying construction performance of the ABWRs built at Shimane, Kashiwazaki and Hamaoka in Japan according to CH2MHill (Worker, 2014). Despite this encouraging evidence, the overall impression remains that nuclear projects are often delivered behind schedule and above budget to the extent that cost overruns and delays seem inevitable features of the industry. However, cost overruns for large and technically complex projects exist also in other industries. In fact, 70% of the costs of a nuclear reactor project are due to civil works, the conventional island and project management, with only 30% due to the nuclear island itself. And some conventional “megaprojects” do well, although cost overruns are typically larger in the energy industry (plus 80%) than in other industries according to the authors of the eponymous study.

This begs the question “Is nuclear different?”, in particular from its peers in the energy industry such as the oil and gas industry. The latter needs also deal with multibillion energy projects in often difficult political and regulatory environments, although it may constitute a more homogenous industry at the global level, thus facilitating both competition and benchmarking. Arguably, the oil and gas industry is also submitted to a level of public scrutiny that is comparable to that of nuclear, at least as far as its operating performance in NEA and OECD countries is concerned. This has led the IAEA to conclude that while series for individual reactors types are typically small, nine out of ten issues in nuclear new build remain the same as in other industries. What can the nuclear industry learn then from other industries, whether the oil and gas industry, the aerospace, the automotive or the logistics industry? One area is project management and logistics. EDF has thus hired as a project manager for its reactor project at Hinkley Point the person who was responsible for the London Olympics as these were widely regarded as a logistical and financial success. The complete traceability of components for more efficient delivery, installation and eventual replacement is another area where the nuclear industry can learn from other industries. Benchmarking and the pooling of industry experience (see the section on project management) is a third area.

Overall, the distinct impression has emerged from discussions that the global nuclear industry is slowly becoming more “normal”, in the sense of having to deal with the challenges of new build under conditions very similar to those of its peers. While a “special” status might have protected national nuclear champions from economic efficiency pressures in the past, today cost concerns rather than safety concerns are driving change in the nuclear industry. In this, the nuclear industry is already very similar to its peers. The next section will look at this question in the particular context of the EU megaproject programme.

III.4.1. The overall performance of megaprojects[1]

A megaproject (sometimes called a large or major project) is an extremely large-scale physical investment project of at least USD 1 billion and having considerable impacts on communities, the environment and shareholder value. They include: •civil infrastructure projects such as railway lines, bridges, tunnels or airports; •oil and gas projects such as refineries, pipelines or liquefied natural gas plants; •power plants, in particular NPPs.

More often than not, megaprojects are characterised by cost overruns and delays. Several scholars have attempted to identify the reasons for such dismal performance. Bend Flyvbjerg and his group have thus studied megaproject performance in the transportation sector (Flyvbjerg, 2006) and Cantarelli has analysed 806 large projects benchmarking the performance of Dutch infrastructure vs. the rest of the world (Cantarelli et al., 2012). A study by Ansar relied on a database of 245 large dams, built between 1934 and 2007 on five continents (Ansar et al., 2014), while 318 megaprojects distributed all around the world costing more than USD 1 billion was the database used by Merrow (2011).

A common conclusion of these studies is that large infrastructure projects are characterised by large cost overruns. Flyvbjerg thus shows an average budget overrun of 44.7% for rail, 33.8% for bridges and tunnels, and 20.4% for roads. Cantarelli reports mean cost overruns of 19.8%, 34.1%, 30% and 35.5% for road, rail, bridge and tunnel projects, respectively. For dams, three out of every four large dams suffered cost overruns and actual costs were on average 96% higher than estimated costs with a median value of 27%. The Ansar study also shows that large dams take significantly longer than planners forecast. About 80% of the projects suffered a schedule overrun and construction times were on average about 44% (corresponding to two years and four months) higher than the estimate. An important conclusion from these analyses is that the accuracy of predictions, whether for cost estimates, construction schedules or even road and rail traffic forecasts, has not improved over time. Whether due to the bias introduced by tendering procedures or due to the inherent complexities of megaprojects, there is apparently little learning from past mistakes.

Ansar’s research also suggests that there is no correlation between regions and cost or schedule overruns. Large dams built in every region of the world suffer systematic cost and schedule overruns. The analysis by Merrow shows a strong dichotomy: few projects are very successful, several unsuccessful. The 35% of the projects that succeeded were genuinely excellent projects. On average, they underran their budgets by 2% while delivering highly competitive (96% of industry average) costs. They were completed on time with schedules that were only slightly (4%) slower than the long-term industry average. Their average production was well ahead of the plan. By contrast, the failures are truly miserable projects: they averaged a 40% constant currency overrun while being very expensive in absolute terms. They slipped their execution schedules by an average of 28% while being 15% slower than a competitive schedule. (Merrow, 2011)

Thus far, research on analysing and comparing nuclear projects with other large infrastructure projects is limited to the work by Mancini, Locatelli and Sainati (n.d.) on “The Effective

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[1] This next two sections are based on a synthesis of Locatelli and Mancini (2010), Locatelli and Mancini (2012) and Locatelli et al. (2014a and 2014b), as well as on the results of the unpublished study for E-COST “The Effective Design and Delivery of Megaprojects in the European Union” by Mauro Mancini, Giorgio Locatelli and Tristano Sainati.

Design and Delivery of Megaprojects in the European Union”, that is based on a network of about 80 researchers from more than 20 European countries. Their dataset is composed of 43 megaprojects including 20 transportation megaprojects and 12 energy projects, of which 4 are nuclear. The latter include the EPR new build projects Olkiluoto 3 (Finland) and Flamanville 3 (France), the completion of the Mohovce 3 and 4 units (Slovakia), and the upgrade of the reactors in Oskarshamn (Sweden). The overall picture is consistent with the results reported by Flyvbjerg and Merrow: megaprojects in Europe tend to be over budget and late. Although the nuclear database consists only of a very limited number of cases and all of them can be considered as FOAK projects, results show the budget overrun of nuclear projects even exceeds the overruns of other large infrastructure projects.

Reasons for cost and budget overruns in megaprojects

In explaining the budget overruns and delays in the delivery of megaprojects, the project technology (NPPs apart), location and construction date have little influence. There are, however a number of recurring features that are identified by different researchers.

Optimism bias and strategic manipulation

Wachs interviewed government officials, consultants and planners in charge of different projects and noted that their estimations were biased (Wachs, 1990). They manipulated forecasts to achieve values that were not justified in technical terms, but acceptable for their superiors to be able to implement the project. Cognitive biases and organisational pressures push managers to provide optimistic forecasts. Flyvbjerg (2006) adds optimism bias inducing promoters to consider each assumption positively. The authors point out, however, that such optimism is misleading for the promoters themselves, and not an intentional error.

Stakeholders mistakes and project characteristics

Merrow (2011) identifies seven “key mistakes” and provides a statistical analysis of the correlations between project characteristics and project performance. The seven “key mistakes” made by the key megaprojects stakeholders are: greed, schedule pressure, poor bidding phase, reductions in upfront cost, poor engineering and design, unrealistic cost estimations and poor risk allocation. Regarding the statistical analysis, the author also shows that the following parameters have strong correlations with project performance: regulatory climate and stability, clear and coherent business objectives, quality and reliability of basic data, radical new technology, project team characteristics, quality of the front-end loading, engineering and design, remoteness of site, contractual forms, incentives, supportiveness of government, risk management, labour availability and project governance.

Project governance

Focusing on the governance of megaprojects, van Marrewijk et al. (2008) argue that the failures of megaprojects are also promoted by scope ambiguity, technical complexity and the involvement of a large number of partners with different cultures and different ways of working. According to the authors, it is possible to improve project performance through better governance and a better definition of the responsibilities of the key stakeholders involved. In particular, they refer to the so-called “control versus commitment dilemma”. When the project organisation exercises dominant control, the partners lose commitment to the project. They feel that they do not have autonomy to make decisions and consider their role focused only on accomplishing the tasks they are in charge of. However, commitment is fundamental to achieve success, so it is necessary to find an optimal compromise between control and freedom.

Intrinsic complexity

Another research stream explains the cost overruns and delays of megaprojects by way of their intrinsic complexity and the complexity of the environment in which they are delivered. Compared to a “simple project” (e.g. a primary school building), megaprojects are often delivered in a project environment characterised by: • rapid technological change and increased risks of obsolescence; • interoperable and interdependent systems; • emphasis on cost reduction; • tight schedules without quality or scope reduction; • integration issues as a high number of system parts, and organisations involved; • combining multiple technical disciplines; • competitive pressures. These seven elements are typical of “complex project environments”. Another metric defines a project environment as “complex” if it has at least one of the following characteristics: • several distinct disciplines, methods or approaches involved in the project; • strong legal, social, or environmental impacts of the project; • the use of a high share of a partner’s resources (absence of redundancy); • strategic importance of the project to the organisation or organisations involved; • stakeholders with conflicting needs regarding the characteristics of the project; • a high number and variety of interfaces between the project and other organisational entities. It is clear that these parameters often apply to megaprojects, in particular the construction of NPPs.

III.4.2. New nuclear power plants as megaprojects

Quite obviously, the construction of a new NPP is a megaproject. A typical generation III/III+ reactor will use 6 000 m^3 of concrete only for the base-mat, 61 000 tonnes of steel and 4 000 tonnes of forgings. To this must be added 5 000 valves, 200 pumps, 210 km of piping, more than 2 000 km of cabling and more than 50 000 welding seams. However, there are other large industrial projects. In this perspective, does nuclear remain special?

Assessing cost reductions and the ability of the nuclear industry to keep up with its peers over time remains a work in progress. Representatives of the EU funded Megaproject research study, who study cost and time performance of a large number of sizeable industrial projects, even dispute on the basis of their statistics that FOAK is a relevant metric. One must also be cautious with ascribing all observable impacts to the internal economies or diseconomies of the reactor builder. As pointed out by Vanbrugh consulting, reactor costs really did come down during the 1990s in many countries. As far as the subsequent cost increases during the first decade of the 21st century are concerned, external factors such as increases in the price of steel, specialised labour and energy played a significant role. Not everything can be controlled. Only two thirds of the costs can be considered as firm at the time of signing the contract; the rest is variable. Fortunately, external influences can go either way. The US DOE thus reported that current outlays at the AP1000 project at the VC Summer plant in South Carolina are *below* projections due to lower than expected financing costs. The current cost of debt is thus 5.7% on average, with a latest tranche of USD 400 million having been placed at 4.6% in June 2013, more than compensating a slight increase in overnight costs. The industry also no longer experiences serious bottlenecks in key components. Even in the area of highvalue segment of large forgings such as the reactor vessel, global supply is currently sufficient, with Japan alone being able to satisfy three quarters of global demand. The research of Flyvbjerg, Merrow and the Megaproject group mentioned above, however, suggests that cost escalation in the nuclear sector might be even higher than elsewhere, in particular looking at the two new European projects Olkiluoto 3 and Flamanville 3. On the other hand, the history of the Korean nuclear programme until its recent brush with quality control issues can be considered an unqualified success. Nuclear programmes seem to display a dichotomy of performance that is stronger than with other type of megaprojects.

Several factors make the projects of building new nuclear reactors unique. Comparing the construction of nuclear reactors with other megaproject (e.g. a new defence system or an international high-speed railway) point to a number of peculiarities, including: • The “safety issue”. A failure/accident in a solar, wind or even coal plant has very local “short-term” consequences, while a nuclear accident can cause a major disaster with a long time-scale. The design and construction of safe reactors is possible, but requires very high quality standards. They also require extreme specialisation with bottlenecks in particular for FOAK projects.

- The variety of disciplines and provenance of the workforce. The design and construction of an NPP include virtually all kinds of hard engineering skills (from civil to mechanics) and managerial skills (finance, project management, health and safety). Moreover, the design and construction involves thousands of people from multiple countries on the site. The blend of disciplines, cultures, languages (and even standards and certifications) represents an extraordinary challenge for organisation. This was a critical aspect at Olkiluoto 3.

- Stakeholder scrutiny. Compared to a large offshore wind farm, the construction of an NPP will attract much more attention from safety authorities, but also the press, political or environmental groups.

The following section focuses on the cost and schedule performance of NPPs. It provides three case studies of nuclear new build at Shoreham (United States), Olkiluoto and Flamanville (Finland and France) and in Korea, and discusses the key lessons learnt.

Shoreham nuclear power plant

The Shoreham NNP was a 820 MW BWR located adjacent to the Long Island Sound in East Shoreham, New York. The plant was built between 1973 and 1984, commissioned, but never operated. The cost famously escalated from USD 75 million to USD 5.5 billion, a factor of roughly 70. Ross and Staw (1993) identify some of the reasons behind this spectacular cost overrun:

- Objective difficulty to estimate the real cost of such a complex and innovative project, in particular as scope creep set in due to legislation changes.

- Sunk cost trap: cost estimates rose exponentially during the project. The US dollar value of each increase was a relatively small percentage of previous expenditures. In addition, most of the expenditures took place when the plant was already 80% completed. Having a nearly completed physical structure probably increased the willingness to invest additional funds.

- Investment lock-in: greater and greater percentage of owner and bank capitals were tied to Shoreham, the plant and the future of the utility became intertwined. The project turned into a “bet-the-company” proposition.

- Psychological determinants included optimism bias, “winner will always win” attitude and a blame culture in which abandoning the project would be shameful for the project team.

- Social determinants may have included cultural factors such as the fact that American society reserves special praise for those who stay a course in the face of hardship, or mimetic behaviour: the company that owned Shoreham was one of the few major utilities in the United States not to have a nuclear power component. They wanted an NPP.

- Organisational determinants: the decision to embark on the construction of an NPP mainly involved people whose primary asset was expertise with nuclear power. Increasingly, the company placed all its hopes in the nuclear basket.

- Contextual determinants: The decision to construct a nuclear plant became larger than the organisation itself, involving forces beyond the organisation’s boundaries, such as political supporters. The role of these external parties and their alliances with the owner cannot be overemphasised.

European new build: Olkiluoto and Flamanville

Locatelli and Mancini focus their analysis on the EPR new build projects Olkiluoto 3 and Flamanville 3 (Locatelli and Mancini, 2012). By examining Olkiluoto 3 and Flamanville 3 for points of similarity, it is possible to posit that the causes of cost over budget and delay can be grouped into the two meta-themes of: *(i)* FOAK effects in a highly regulated environment; and *(ii)* over-optimistic forecasts.

FOAK effects for megaprojects

It may seem strange to define two EPR construction projects using the same technology of FOAK projects. However, even if the technologies are the same, the two projects are executed by separate supply chains, parts of which were unfamiliar with the regulatory context, and each one of which experienced its own significant FOAK issues. In nuclear engineering projects, the architect/engineer plays a key role in the performance of a project particularly in terms of managing project information. In the case of Olkiluoto 3, AREVA was, for the first time, the architect/engineer of a nuclear construction project. In the case of Flamanville 3, EDF has a long history of having built and commissioned 44 GW of nuclear capacity. The last unit built in France however started commercial operations in 2002, although construction had been completed in 1999. The EPR is a new technology and caused many FOAK issues even for an experienced architect/engineer such as EDF. Furthermore, EDF used a new and untested supplier network. FOAK effects in the supply chain were thus in evidence in both cases. In Flamanville 3 and in Olkiluoto 3, the regulatory authorities (the Nuclear Safety Authority [ASN] and Finnish Radiation and Nuclear Safety Authority [STUK] respectively) held up construction because of the insufficient quality of the work undertaken by inexperienced contractors (Ruuska et al., 2009).

Over-optimistic forecasts

In both projects, the original estimates were significantly below the actual time and resources required. Grubler argues that the initial 2005 forecast for the EPR at Flamanville was too optimistic if compared to the previous costs of reactors built in France, in particular considering that an increase in size increases construction time, and the EPR is the largest reactor ever built. Moreover, the EPR is based both on the German Konvoi reactor and the French N4 reactor. Already, building the N4 reactor had proven difficult as it faced numerous technical difficulties, substantial delays, and by French standards, significant cost overruns. Looking at the values for the N4 reactor in Table 29 and in Figure 41, it becomes clear that the initial forecasts were too optimistic. The previous reference reactors had been completed in about ten years during an era in which dozens of reactors had been built, when the entire project delivery chain was experienced and FOAK effects had been minimised.

The new EPRs are bigger, more complex and built by inexperienced supply chains. Nevertheless, the initial estimation forecasted a 50% reduction in the construction schedule. The forecasts for both Flamanville 3 and Olkiluoto 3 clearly demonstrated optimism bias. EDF Energy (a UK company owned by EDF) has now advanced plans for the construction of two EPRs in Hinkley Point (Somerset, England). EDF Energy applied for consent to construct and operate the two EPRs in October 2011. In October 2013, the government announced that initial agreement had been reached with EDF Energy on the key terms of a proposed GBP 16 billion investment contract for the Hinkley Point C nuclear power station. The sum of GBP 16 billion corresponds to EUR 20 billion, a number not very far from the current and possibly final estimates for the total combined costs of Olkiluoto 3 and Flamanville 3. The new cost estimates are thus consistent with a “reference class forecast” approach.

Table 29: Cost and construction times of N4 and Konvoi reactors

Type	Location	Net capacity (MW)	Construction started	Connected to grid	Commercial operation	Constr. time (years)	Cost[1]	Cost[2]
N4	Ardennes	1 500	01/1984	08/1996	05/2000	12.7	2.41	5.01
N4	Ardennes	1 500	12/1985	04/1997	09/2000	11.3	2.56	5.32
N4	Vienne	1 495	10/1988	12/1997	01/2002	9.2	2.56	5.32
N4	Vienne	1 495	04/1991	12/1999	04/2002	8.7	4.82	10.02
Konvoi	Brokdorf	1 410	01/1976	10/1986	12/1986	10.8	n.a.	n.a.
Konvoi	Philippsburg	1 402	07/1977	12/1984	04/1985	7.5	n.a.	n.a.
Konvoi	Isar	1 410	09/1982	01/1988	04/1988	5.4	n.a.	n.a.

1. Historic, EUR billions.

2. EUR billions in 2011.

Source: IAEA, 2014 and Grubler, 2010.

Figure 41: Construction times in comparison

The Korean experience

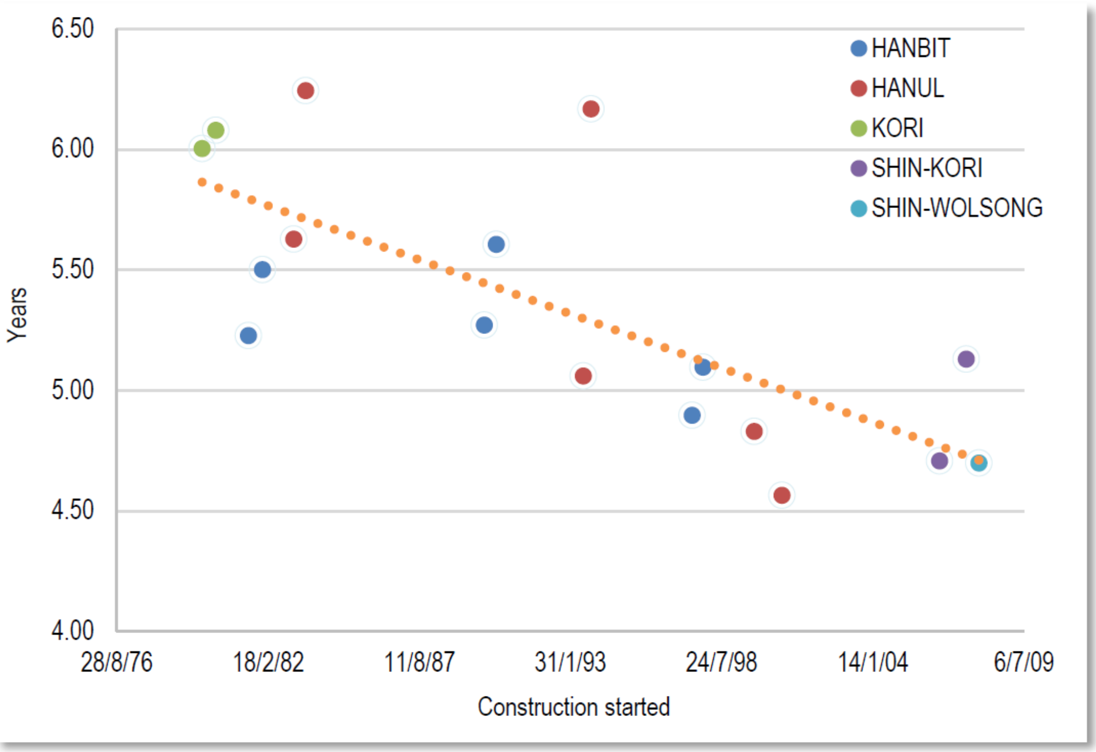
Nuclear experts agree that the (pre-2000) French and Korean NNB programmes are success stories. In both countries, a cohesive group of organisations constituted the project delivery chain and, after the definition of a standard design, successfully delivered several power plants. These countries established network relationships to deliver a "nuclear programme" (i.e. several, almost identical, reactors) rather than individually commissioned power plants. Most of the time, the architect/engineer and the subcontractors were able to deliver the reactors on time and on budget, the French N4 reactors being an exception.

In large projects, especially in the nuclear field, a key strategy to achieve good performances appears to be the standardisation of the project delivery supply chain and reactor design (Locatelli et al., 2014b). This is an insight that applies well to the Korean new build programme. Figure 42 shows the very good performance in terms of construction times of the Korean nuclear programme (IAEA, 2014).

In addition to standardisation, Choi, et al. (2009) summarise a number of lessons to explain the success of the Korean experience:

- integration of extensive knowledge and experiences;
- strong national commitment to the nuclear power programme;
- continuous investment in the infrastructure with government leadership;
- localisation through technology transfer (as discussed above);
- clear definition of responsibilities and rights in the NPP construction.

Figure 42: The Korean pressurised water reactor programme



Concluding considerations on delivering successful megaprojects

In order to enable the realisation of complex systems, such as an NNB project in multidimensional environments, multidisciplinary approaches such as system engineering are required. The latter provides a somewhat broader approach to classic project management and includes aspects such as shared leadership, social competence and emotional intelligence, communication, skills in organisational politics and the recognition of the importance of visions, and values. The modern origins of system engineering can be traced to the 1930s, but the first significant developments were in the early 1950s when the US Department of Defence needed to deliver large, complex projects respecting time, budget and quality.

To achieve these ambitious targets, standard project governance was no longer enough and "project governance" had to evolve into "system governance". The focus of system engineering is in particular on the earlier project stages. These stages are the project definition (scope management), project stakeholder management and project planning (all aspects related to the project governance). These are key aspects in the nuclear field, and include the decision on the reactor size (a multidimensional problem requiring the evaluation of several aspects), the definition of the best supply chain configuration for the local culture and political configuration (including all external stakeholders), or the realistic overall plan without biases from personal or ideological interests.

The nuclear sector presents the highest level of technical complexity compared to other industrial sectors such as oil and gas, pharmaceuticals or food manufacturing, which makes paying attention to managerial topics particularly important. When analysing both the past performance of nuclear projects and nuclear incidents, most of them can be traced back to managerial mistakes, not to technical ones. In the past, these considerations were addressed by giving managerial positions in the nuclear delivery chain to very good managers coming from other sectors. However, the peculiarities of the nuclear industry cannot be fully appreciated with just theoretical training. On-hand experience remains a fundamental asset. a long-term objective, even if it is not a simple and quick process. The managerial evolution of the military and aerospace supply chain can be considered as a benchmark, since they are from an organisational point of view comparable to the nuclear industry. However, very clearly there is no magic bullet. Megaprojects are frequently over budget and late all over the world in many different sectors. There has been little or no improvement over the decades. Project performance today is roughly similar to ten, twenty and thirty years ago. On the other hand, even if public opinion and the press are focusing on nuclear projects being over budget and late, such poor performance is not a fatality. The Korean and the (pre-2000) French experience shows that it is possible to deliver nuclear projects on time and budget. Key success factors are the replication of existing reactors, a relative monoculture, a stable environment with experienced stakeholders and a long-term view. Some of these factors may no longer be replicable and the most promising way forward may be to start learning from other high technological sectors such as aerospace or oil and gas, where a number of major companies have evolved from national champions to global competitors.

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