International Transport Forum

Risk Allocation in Mega-Projects in Denmark

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Foreword

Transport infrastructure is a major enabler of economic development. In the drive to refurbish or build more, governments worldwide have turned to the private capital market to help finance it. The primary narrative behind this push is that there huge stocks of private capital available, while public financing capabilities are said to be limited and insufficient.

The almost exclusive vehicle of private investment in transport (and social) infrastructure are Public-Private Partnerships (PPPs). In the context of PPPs, two important aspects have received little attention.

First, sufficient attention has not been given to the role of suppliers. The focus of, governments and Intergovernmental Organisations has been on resolving the challenges to private investment from the viewpoint of investors; a key part is reducing uncertainty they face and enabling them to price risk more efficiently (establishing infrastructure as an asset class).

Yet looking at the investors only gives an incomplete view of the total cost of the risk transferred from the public to the private sphere. In PPPs investors transfer some of the major risks they are not comfortable bearing (e.g. construction risk) to design, construction, maintenance, and operations contractors.

As investors, suppliers too face uncertainties and can't price risk efficiently. In such a case, the base cost of the initial investment (and of subsequent services) will be much higher than they could be, and not just the cost of their financing.

Uncertainty arises from the difficulties to accurately estimate the cost of construction, maintenance, operations, and financing. But it also stems from "unknown unknowns" (the so called Knightian uncertainty), for instance changes in weather patterns or paradigmatic technological shifts the timing and impact of which are unclear but will influence what infrastructure is needed and where.

So what can policy makers do to reduce the cost of inefficient risk pricing of suppliers? Where does this put PPPs? How can public decision makers reconcile long-term uncertainty with private investment in infrastructure? Who should bear long-term uncertainty in projects, the public or the private sector?

These were some of the guiding questions for a Working Group of 33 international experts convened by the International Transport Forum (ITF) In September 2016. The group, which assembled renowned practitioners and academics from areas including private infrastructure finance, incentive regulation, civil engineering, project management and transport policy, examined how to address the problem of uncertainty in contracts with a view to mobilise more private investment in transport infrastructure. As uncertainty matters for all contracts, not only those in the context of private investment in (transport) infrastructure, the Working Group's findings are relevant for public procurement in general.

The synthesis report of the Working Group was published in June 2018. The report is complemented by a series of 19 topical papers that provide a more in-depth analysis of the issues. A full list of all Working Group papers is available in Appendix 1.

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Executive summary

What we did

This paper looks at three high-profile infrastructure mega-projects in Denmark: the Storebælt and Øresund fixed links and the planned Fehmarnbelt fixed link. It specifically describes the evolution of the approach to risk allocation in procurement and construction taken by Sund & Baelt Holding A/S for the civil engineering parts of these projects. Risk allocation is a decisive factor in any major construction project. Clear and rational risk allocation is an important driver of value for money. It is well understood that a risk should be carried by the party best suited to mitigate and/or manage the particular risk. However, practical implementation of this rule is not by any means a simple exercise.

What we found

Risk analysis is an essential step on the road to effective risk allocation. Risks must be understood in order to allocate them correctly. The owner's fundamental choices affect the outcome the most. The politically driven decision to construct a bored tunnel on Storebælt rather than an immersed tube tunnel, notwithstanding the findings of the risk and other assessments, proved to be hugely significant. No matter how robust or well-founded the risk allocation is after that, there is no escaping the fundamentals of the risk that you have taken on.

Using design and build contracts can bring great benefits. The interplay between design and method risks and opportunities can be well managed by the contractors to everyone's benefit. Where risks are to be transferred, it is vital that in the procurement stage the bidders have the best information possible to assess and manage the risk. Here, the contractor's fundamental choices at the tender stage will affect the outcome the most.

Risk allocation should be stated clearly and unambiguously in the contract documents. Time taken to prepare for procurement is time well spent. The benefits of using performance requirements in contract documents can be seen. But this must be appreciated as an art and not a science; sometimes there is no black-and-white answer. The owner must walk the line between functional requirement and specification. As always, it is important to know what your interest is and have a mature attitude to risk. Environmental risk, for example, is unable to be truly transferred, and the owner should take responsibility where they need to.

Competitive dialogue, as provided for in the procurement regulations, can be a useful part of the risk allocation process, building a common understanding and providing a forum for constructive give-and-take, but it is time consuming and requires the right skills from both the owner and contractor.

What we recommend

Determine which party is best able to prevent and mitigate a risk through analysis, not a premade template

Take time before procurement to analyse and understand risks, to make the best choices and develop the most effective risk allocation. This involves preparing good quality documents and allowing sufficient time for the procurement processes. Risk-related information should be shared early in the tender process by establishing a joint risk register.

Work with the bidders in complex schemes to better understand risk

Consult the market as appropriate, for example through structured market engagement pre-procurement or as part of the procurement process (e.g. under the competitive dialogue procedure). Build a common understanding of risk and optimise risk allocation.

Mind your interests in risk allocation and don't get caught up in micromanagement

Maintain a clear view of what your interests are and have a mature attitude to risk. Where appropriate, use input rather than output specifications if this will better manage whole-project risk. The role of the owner is to lead the process not manage it in detail. Exercise control by strategic intervention.

Remain in close contact, and vigilant, even once risks have been allocated.

Do not be lulled into a false sense of security. It is true that risk assessment and risk management have become more sophisticated over the life of Sund and Bælt's projects and contractors have become hugely skilled in managing the risks that are allocated to them. ISO standards have established a common language and a level of quality and IT systems allow risks to be monitored and tracked in collaborative online environments. However, never forget that in the real world, in order to avoid a hazard, you are reliant upon the people on site. And simple errors like a hatch being left open can have serious consequences. Always be vigilant and communicate, communicate, communicate.

Introduction

Sund and Bælt has been responsible for three high-profile mega-projects for combined road and rail traffic in the last 30 years: the operational Storebælt and Øresund fixed links and the planned Fehmarnbelt fixed link.

This paper describes the evolution of Sund and Bælt's approach to risk allocation in the procurement and construction of the civil engineering parts of its infrastructure.

Figure 1. The locations of the Storebælt, Øresund and Fehmarnbelt fixed links

The fixed links

The Storebælt fixed link connects Denmark's largest island, Zealand, where the capital Copenhagen is located, to the second largest island, Funen. It crosses the Storebælt strait, the widest and deepest of the three straits that connect the Baltic Sea to the North Sea. Before its construction, Denmark was divided into two regions, east and west (Funen having been connected since 1935 to mainland Jutland in the west by the Lillebælt bridge). The fixed link has become a vital part of Denmark's transport infrastructure and economy, creating opportunities for businesses and individuals.

The Øresund fixed link connects Denmark and southern Sweden across the Øresund strait. It opened to road and rail traffic in 2000 and is an important part of Denmark and Sweden's transport infrastructure. It provides connectivity between the Copenhagen area and southern Sweden and was a game-changer in the creation and growth of the Øresund economic region.

The Fehmarnbelt fixed link will be a road and rail tunnel between Lolland in Denmark and Femern in Germany. It will create opportunities for businesses, commuters and tourists and will be the backbone of a new European economic region. It will increase flexibility and accessibility, reducing travel time by train between Hamburg and Copenhagen to 2.5 hours from 4.5 hours today. Travel time by road will also be reduced.

Table 1. Facts about the Storebælt, Øresund and Fehmarnbelt fixed links

	Storebælt	Øresund	Fehmarnbelt
Length	18 km	16 km	18 km
Principal elements of coast-to-coast link	West (low) bridge carrying road and rail traffic Road and railway on the island of Sprogø in the middle of the strait East (high) bridge carrying road traffic East tunnel carrying rail traffic	Road and rail tunnel in the west section Road and rail on the artificial island of Peberholm Two-deck road and rail bridge in the east section	Road and rail tunnel
Political approval	1987	1991	2008
Construction start	1988/89	1995	Planned for 2020
Open to traffic	1997/98	2000	Planned for 2028
Debt at opening (2017 prices)	EUR 6.8 billion	EUR 3.4 billion	Estimated EUR 7.4 billion
Estimated repayment period	34 years	33 years	36 years

The Storebælt fixed link

In June 1987, the Danish parliament passed the Construction Act for a fixed link across the Storebælt. This was the culmination of a debate lasting decades about the link. An important feature of the act was that the link was to be built in two stages such that the railway would open three years before the road. This arose from a political wish to give public transport a head start over car traffic. The railway was planned to open in 1993 and the road in 1996.

The act described the fixed link in four different sections. The west section of the link would comprise a low-level bridge carrying both rail and road across the western channel between Funen and the island of Sprogø. In the central section, rail and road would run on the island of Sprogø. The east section for rail would comprise either a bored or an immersed tube tunnel across the eastern channel between Sprogø and Zealand, and the east section for road would run either on a high-level bridge (with various structural solutions being authorised) or in an immersed tube tunnel.

Thus, the form of the structure of the west section was not defined. In the east section, the act identified a number of alternatives for the infrastructure, based on the feasibility and option studies that had at that time been carried out. The preferred alternative would be selected based on further investigations (including risk assessments) and on the bids received in the later procurement processes.

Also in 1987, the owner organisation (which was later incorporated into Sund and Bælt) was established and was made responsible for the design, procurement, construction and operation of the fixed link. The owner organisation was owned by the Danish state.

The procurement stage

For procurement, the fixed link was divided into a number of tender packages:

- West Bridge for road and rail.
- East Tunnel for rail (either bored or immersed tube tunnel).
- East Bridge for road. As noted above, the act also provided for an immersed tube tunnel option for the east section, but this was not taken forward to procurement. Further investigations, including in the light of prices received for the immersed tube tunnel alternative for the east tunnel, meant this option was rejected. For procurement, the East Bridge was further divided into four sub-packages.

The common features of the procurement processes are described below.

Joint-venture consulting engineers produced the tender documents and for-tender design. Design was carried out on the basis of earlier concept design and option-study stages that had, among other things, informed the drafting of the Construction Act.

The tender documents consisted of the contract conditions, technical requirements, tender drawings and bills of quantities, together with instructions to tenderers for submitting bids.

The tender documents reflected the findings of the owner's risk assessments. In the course of preparing the for-tender design, the owner carried out construction risk assessments. The owner also carried out operational risk assessments, which focused on events that might lead to traffic disruption or fatal accidents to users. The results and, in particular, any mitigation measures were incorporated into the for-tender design and tender documents.

The owner's Design Basis was included in the tender documents in order that bidders understand the requirements and better prepare their bids. The Design Basis identified the owner's most fundamental functional requirements, the cross section, alignment, codes and standards, etc. However, it was not simply a technical document; it also reflected the owner's risk assessments and the future importance of the fixed link in Denmark's transport infrastructure and economy. It set out the basis for safe and robust design with a reasonable redundancy and factor of safety against extreme loading and events. These included ship impacts, ice loading, loss of durability and accidental loads from rail and road. It was based on a range of studies covering geology, hydrogeology, tunnelling methods, durability, loading, railway operations and safety.

All contracts were procured by inviting tenders from pre-qualified joint-venture contractors.

Bidders were required to submit bids for each of the owner alternatives that were identified in each package. This resulted in a large number of bids being required.

Bidders were also able to submit "bidder alternatives" and "bidder variants" (alternatives being major changes to the form of the structure and variants being narrower changes to the technical requirements). This approach was taken to get the most benefit from the contractor's expertise and in recognition that methods are as much a driver of cost and quality as design.

Design risk was to be retained by the owner.

The tender documents did not include detailed design drawings and specifications but rather higher level general arrangements and functional requirements. Detailed for-construction design and drawings would be issued to the contractor during the contract.

Work would be remeasured using the priced bills of quantities in the bid. Thus, given the level of detail of the tender documents, there was relatively low cost certainty.

The owner made geotechnical data available in the tender documents based on geotechnical investigation along the link's alignment (from 25 years of geotechnical investigations and tests in the area of the fixed link). Furthermore, the owner supplemented this with additional investigations and tests (in situ and in the laboratory) performed by specialists with experience of the prevailing difficult ground conditions. All data was made available in a 3D-geomodel. A general description of the soil conditions was included as an appendix to the Design Basis. The information also incorporated interpretative reports made by the owner's consulting engineers. The eventual contractors would supplement this information with their own investigations as necessary.

The owner retained the risk of geotechnical conditions that that could not reasonably be foreseen by an experienced contractor on the basis of the available data. The large volume of descriptions and data that were provided at tender were to be used as the reference for determining whether actual conditions could have been foreseen.

The owner evaluated the bids on a quality/price basis. Quality criteria included robustness of the management systems and construction methods.

Risk-based adjustments were made to the bid price for the purposes of evaluation to reflect qualifications and reservations in the bids. These adjustments were discussed with bidders at the contract negotiation stage. The Design Basis, and in particular the risk assessments and studies behind it, were useful in assessing the contractor alternatives and variants.

In parallel with the tender assessment, the owner carried out a quantitative risk assessment of their retained risks for each of their alternatives. During the tender assessment, these assessments were refreshed to reflect particular aspects of the bidder's proposals. Where bidders submitted alternatives and variants, new risk assessments were carried out.

Contracts were based on general and specific conditions forming an appendix to the Danish General Conditions for Construction Work (i.e. based on a standard type of Danish contract).

The contractor was responsible for executing the works in accordance with the contract, irrespective of whether the contractor used methods proposed in the tender or other methods. The contractor was responsible for all quality management and quality assurance regardless of whether the owner carried out any supervision, inspection or audit.

Particular features of each of the procurement processes and their outcomes are described below.

West rail and road bridge

In November 1987, the owner appointed a consulting-engineer joint venture to prepare for-tender designs and tender documents for three west bridge alternatives. The alternatives were identified in an earlier concept design and option-study stage. The three alternatives were a concrete bridge, a steel bridge and a concrete/steel composite bridge. Two foundation (caisson) alternatives were also identified. Tender documents for each alternative were subdivided into three packages: substructure, prefabrication of superstructure and transport and erection of superstructure.

In April 1988, tender documents were issued to five pre-qualified bidder joint ventures.

Bids were received from all five bidders in November 1988.

- Each bidder submitted five separate bids for the owner-identified alternatives.
- The bidders collectively submitted a further seven alternative structural arrangements.
- The bidders also submitted seven variants to the various alternatives.
- Collectively, 40 bids were received.

On the basis of the tender assessment and the assessment of retained risks, a bidder alternative was selected as the most economically advantageous bid.

The contract was signed in June 1989. The contract took account of various contract negotiations, including a revised alignment and bridge length (optimised with respect to embankment lengths and compensation dredging) and adjustments that had to be made to the bidder alternative. The design ship collision loads were also revised based on the findings of a risk assessment.

Importantly, the contract also reallocated design risk – the contractor became responsible for the design. This was a natural outcome of the bidder's alternative being accepted. Detailed for-construction design and drawings would be prepared by the contractor. The owner's consulting engineer would be responsible for reviewing the contractor's design and execution documents against owner requirements. Also, again, as a natural outcome of accepting the bidder alternative, the contract was on a lump sum basis rather than the traditional remeasured basis.

East rail tunnel

In July 1987, the owner appointed two consulting-engineer joint ventures to prepare for-tender designs and tender documents for the east tunnel alternatives, a bored tunnel (comprising two bored railway tubes with cross passages) and an immersed tube tunnel in either steel or concrete.

In early 1988, tender documents were issued to four pre-qualified bidder joint ventures.

The geotechnical information was supplemented by a special study on the probability of finding rocks during tunnel boring.

The tender documents reflected the following specific findings of the owner's risk assessments:

- Choice of tunnel boring machine (TBM) type. Based on its assessment of the geology and risk of delay, earth-pressure-balanced tunnel boring machines were required.
- Number of TBMs. Based on its programme risk assessment, four TBMs were required. This would allow two TBMs to work on each individual bore from each end, improving progress and providing some redundancy against problems with individual machines.
- Geotechnical risk. The owner retained the risk of geotechnical conditions that could not reasonably be foreseen by an experienced contractor on the basis of the available data.

- The contractor would be responsible for all aspects of TBM performance (rate of drive, erection of tunnel lining, etc.). Relief would only be given in the event of owner's geotechnical risk occurring.

Bids were received from all four bidders in July 1988.

Each bidder submitted a base bid for the bored tunnel. The bidders also collectively submitted six variants that included the use of only two TBMs (with a resulting longer construction period), a different type of TBM and changes to the tunnel lining and distance between the tunnel bores.

The four bidders also submitted bids for the concrete and steel immersed-tube tunnel alternatives. For each of these alternatives, the bidders were required to provide three bids relating to different arrangements of an artificial peninsula at the tunnel ends (changing the tunnel length). Bidders submitted variants covering different ballasting arrangements, joint details and dredging methods.

For the bored tunnel, the variants for the use of only two TBMs were rejected on the basis of the owner's risk assessment (risk of delay) despite the lower bid price. The variant for the different type of TBM was rejected on the basis of a risk assessment as to its ability to withstand the ground conditions. Other variants covering the tunnel lining were evaluated and accepted. In order to inform the choice of the durability solution, the owner had required bidders to choose between using an epoxy-coated reinforcement or coating the inner and outer surfaces of the tunnel linings. A coated reinforcement was chosen by all bidders on the basis of the risk of damaging the surface coating during handling.

For the immersed tunnel, the steel solution was found to be the most advantageous. The bidder variant for joint detail was acceptable.

Contract negotiations were held with the bidders to clarify aspects of the bids and discuss the qualifications, reservations and the risk adjustment.

The owner carried out a quantitative risk assessment of its retained risks for each of the alternatives. This showed that the contingency required for the bored tunnel alternative was 65% higher than for the immersed tube tunnel.

Notwithstanding the findings of the tender assessment, risk assessments and likely higher outturn cost, a political decision was taken to adopt the bored tunnel alternative. This was in order to avoid the excavation on the seabed required for the immersed tunnel. Therefore, the most economically advantageous bored tunnel bid was selected.

The contract was signed in November 1988.

East Bridge

In spring 1989, the owner appointed a consulting-engineering joint venture to prepare for-tender designs and tender documents for the east bridge. An earlier concept design and option-study stage had identified cable-stayed and suspension bridge solutions as viable. During early tender design, a suspension bridge was identified as the preferred alternative for the main span. Thus, unlike the other tenders only one alternative was tendered. However, within this alternative there were construction alternatives for specific parts of the structure: the pylons could be either steel or concrete; anchors blocks could be precast or cast in situ; and cable erection method could vary. For the approach spans, steel or concrete alternatives were tendered.

For procurement, the east bridge was divided into four sub-packages:

- suspension bridge superstructure (deck, cables, etc.)

- suspension bridge pylons and substructure
- approach bridge superstructure (steel or concrete)
- approach bridge piers and substructure (supporting either steel or concrete).

In June 1990, tender documents were issued to eight pre-qualified bidder joint ventures.

Bids were received from all eight bidders in December 1990.

The eight bidders collectively submitted a total of 32 bids. This included five bids for the suspension bridge superstructure and five bids for the substructure. The remaining bids covered the approach bridge alternatives. The bidders submitted alternative structural arrangements (span lengths and form of construction). The bidders also submitted variants to the various alternatives (prefabricating piers, using higher strength steel to reduce weight, etc.).

On the basis of the tender assessment and assessment of retained risks, the steel alternative for the approach bridge superstructure was selected. The bidder alternative/variant to increase the span length and use high strength steel was found to be the most economically advantageous, and the contract was awarded on that basis. The same bidder won the contract for the suspension bridge superstructure. The contracts for the suspension bridge pylons and substructure, and approach bridge piers and substructure were awarded to another bidder.

The contracts were signed in October 1991. Design risk was retained by the owner despite the fact a bidder alternative for the approach bridges had been selected. The bidder had offered to take responsibility for detailed design, but this was not preferred because of the interface to substructures from another contractor. It was considered that the owner’s consulting engineer could implement the bidder alternative. The contracts were traditional remeasured contracts rather than lump sums.

Construction stage

This section describes risk-specific aspects of the construction stage. During construction, the owner continued to carry out construction risk assessment, building on the pre-tender construction risk assessments but now able to address the contractor’s chosen methods and programme.

West rail and road bridge

The contractor’s chosen method involved prefabrication of bridge caissons, pillars and deck girders in a purpose-built waterfront production facility at Lindholm near the western end of the West Bridge alignment. This was found to bring great benefit in reducing risk because construction was carried out in controlled conditions rather than in the strait.

On the other hand, construction was fundamentally dependent on the heavy-lift crane Svanen, which was used to transport and place all of the caissons, pillars and deck beams. As part of the construction risk assessment, hazards were identified, including failure of lifting gear, collision with the load-out jetty and collision with third-party vessels. Risks were assessed and mitigation measures were introduced as necessary, and the risk assessment informed the review and the comment on the contractor’s method statements. When Svanen was transported across the then existing ferry route, special measures were introduced for communications.

Figure 2. The West Bridge across the Storebælt

East rail tunnel

Driving a bored tunnel in the prevailing ground conditions proved to be even more difficult than had been assessed in the various risk assessments. The impact of this difficulty was compounded by events caused by human failure. These difficulties and events are described below. What is also described is how the owner responded. Recovering from these events required the owner and the contractor to be active and flexible and to not simply sit back and allow the mechanisms of the signed contract to run their course. Despite these actions the project was significantly delayed.

The specialist manufacturer of the TBMs proved unable to meet the challenging programme. In trying to manufacture four large machines at the same time, quality control suffered. While these were manufacturer risks, the main contractor and indeed the owner placed staff at the manufacturing facilities to better monitor the work. The owner also renegotiated some aspects of the programme. While this allowed for some extension of time (removing the threat of damages), it also required some of the already incurred delay to be recovered by accelerating the pace of work in return for increased payment. In the event, delivery to site was still delayed.

After only a very short period in operation, the first TBM was found to have a serious defect. Filings and shavings from the welding and fabrication processes had contaminated the hydraulic systems. The pumps and equipment were stripped from all four machines and returned to the manufacturer for cleaning. This further delayed the work.

After a short period of running-in and driving the machines in the actual ground conditions, and against the backdrop of the manufacturer delays, the owner and contractor negotiated a change to the risk sharing with respect to ground conditions and TBM progress. As noted previously, the contractor was responsible for TBM progress and the owner bore the risk of unforeseen ground conditions. In the new agreement, rates of progress were defined, but the owner shared the risk if progress was slowed by more than 10% (as a result of the difficult ground). In addition, an element of risk sharing was introduced around the replacement of cutter heads. This new agreement reflected the real-world reality that driving the tunnel was proving to be more difficult than expected and that sitting back and arguing about the foreseeability or unforeseeability of ground conditions or the TBM problems would not recover the situation.

In October 1991 the tunnel bores on the western side both flooded. The flood occurred when the excavated face at the front of one of the TBMs failed, a hydraulic connection to the sea above was formed (i.e. a void opened up and the sea floor collapsed in) and water flooded in. Maintenance was being carried out on the screw conveyor, and the bulkhead door and manlock had been left open in contravention to the written procedures. Later investigation suggested that a false sense of security had crept in because in the early advances of the TBM the excavated face had been stable.

Against the backdrop of the now significant delays, the owner and the contractor developed Project Moses in response to the problems in driving the tunnel in difficult ground conditions. Tunnelling in the tills was difficult in pressures above 2bar. In addition, the frequent replacement of the cutter heads had to be carried out in compressed-air working, and this would be impossible as the pressure increased. The project involved the large-scale dewatering of the seabed along the alignment of the tunnel to reduce the pore water pressure. It was conceived after observing that during dewatering of the ramp area on Sprogø, the groundwater level was lowered over a considerable distance. The project involved the owner, contractor and geotechnical specialists working together to trial and then implement the full-scale dewatering.

In June 1994 a fire broke out in one of the TBMs; the most likely cause was a burst hydraulic hose and burning hydraulic oil. The fire activated a gas-alarm that tripped the main power supply, but unfortunately the sprinkler and foam systems were not connected to the emergency power supply. The TBM was evacuated. The fire department was unable to access and extinguish the fire, and it was not possible to reach the front of the TBM until 36 hours later. A length of installed tunnel-lining was found to be severely damaged. The fire delayed tunnel construction by 9 months.

In the aftermath of the fire, a HAZOP (Hazards and Operability) study was carried out on all working procedures, with a focus on personnel safety. The study was carried out by a working group including the owner, contractor, consulting engineers, safety officers and a number of safety specialists.

The tunnel construction was ultimately completed approximately three years late.

East Bridge

Construction involved prefabrication of bridge caissons in purpose-built production facilities at Kalundborg and Halsskov near the East Bridge alignment. The construction risk assessment showed this to bring benefit in reducing risk because construction was carried out in controlled conditions rather than in the strait. On the other hand, transport by sea was found to bring its own hazards.

A specific construction risk assessment for marine traffic was carried out. Risks were assessed and mitigation measures were introduced as necessary; the risk assessment informed the review and the comment on the contractor’s method statements. The owner introduced a vessel traffic system in the strait, including two guard ships.

Figure 3. The East Bridge across the Storebælt

Observations

The following observations can be made. Bidders were required to submit a large number of bids. This placed a considerable burden on the bidders and very likely affected the quality of their bids, including their assessment of the risks. On the other hand, it allowed the owner to market-test their alternatives to identify the most economically advantageous, including as regards risk. However, it would have perhaps been better to have spent more time sifting through the alternatives before procurement. The greater time taken to study the East Bridge before procurement can be seen to have been beneficial here.

A relatively short time was allowed for bidding. To take the East Bridge as an example, six months to prepare multiple bids is a challenge; doing so in a joint-venture bid group is a greater challenge.

The tender documents did not include detailed design drawings and specifications, and the contracts were to be remeasured against the priced bill of quantities. There is nothing inherently wrong with this approach, however, a mature attitude to risk and contingency is needed because cost certainty is low. That said, providing more detail to achieve greater cost certainty would have required more pre-procurement time, and the short period between political approval (1987) and construction (1988) is worth noting.

The owner was flexible in their approach in pursuit of best value where they needed to be. The allocation of design risk for the West Bridge was changed where analysis showed it offered value for money.

Where they needed to be, the owner was rigid in their approach. For the East Tunnel, the pre-procurement studies and risk assessments meant that the owner held-firm and rejected the variants for number and type of TBM.

Parts of the fixed link were broken into more packages than would be the norm today. It is very unlikely that an owner would divide a suspension bridge into separate packages for superstructure and substructure. Indeed, this approach was not used for Øresund, and Fehmarnbelt also uses large one-contractor packages.

The decision to choose a bored tunnel for the East Tunnel is worth noting. The findings of the risk assessments, including the quantitative risk assessment of owner-retained risks, was overturned by the political/environmental consideration to avoid dredging a trench for an immersed tunnel. The bored tunnel proved to be much harder to construct than had been thought. Incidents of human error caused other catastrophic events. And the outturn owner's costs were considerably above what had been estimated in the risk assessment. It is interesting to reflect on whether the same decision would be made if the estimates had been nearer the outturn.

The construction stage demonstrates the potential benefits of prefabrication as compared to in-situ construction. For the bridge structures, prefabrication on land was used as much as possible. This provided better and safer working conditions and secured higher quality, especially for the concrete, where high durability was required and strict temperature and moisture control was necessary during hardening. However, transport by sea was found to bring its own hazards, which needed to be managed.

While the East Tunnel was by no means a success story, the owner and the contractor could feel some pride on how they responded to the problems. Recovering from these events required the parties to be active, flexible and capable of solving problems. Sitting back and expecting the mechanisms in the contract to solve the problem was not an option. It is a credit to the positive approach of the parties that issues were ultimately settled amicably and without recourse to the courts.

Øresund fixed link

In March 1991, Denmark and Sweden signed a treaty for the establishment of a fixed link across the Øresund strait. That same year the Danish parliament ratified the treaty in a public works act and established Sund & Bælt Holding A/S. The treaty defined the overall requirements for the fixed link, including alignment, design speeds and environmental constraints. It also defined the principal civil engineering elements of the link:

- reclaimed (artificial) peninsula at Kastrup on the Danish side
- immersed tube tunnel under the Drogden channel
- reclaimed (artificial) island Peberholm to the south of the island of Saltholm
- bridge between Peberholm and Sweden crossing the Flinte channel (comprising a west approach bridge, a high bridge and an east approach bridge).

A tunnel was selected for the crossing between Kastrup and Peberholm because the alignment of the link is under the flight path to Copenhagen Airport and tall bridge pylons were not acceptable. An immersed tube tunnel was selected rather than a bored tunnel because of the diverse and difficult tunnelling conditions in the Drogden channel. The relatively shallow depth of the channel also lends itself to an immersed tube tunnel. It is worth noting that by the time of this decision the problems with the bored tunnel on Storebælt were starting to become evident.

Figure 4. The Øresund bridge and island, with the tunnel portal in the foreground

In 1992, Øresundskonsortiet was established to oversee the coast-to-coast section of the link. Øresundskonsortiet is 50% owned by Sund & Bælt Holding A/S and 50% owned by a Swedish state company.

Procurement stage

For procurement the civil engineering elements were divided into the following packages:

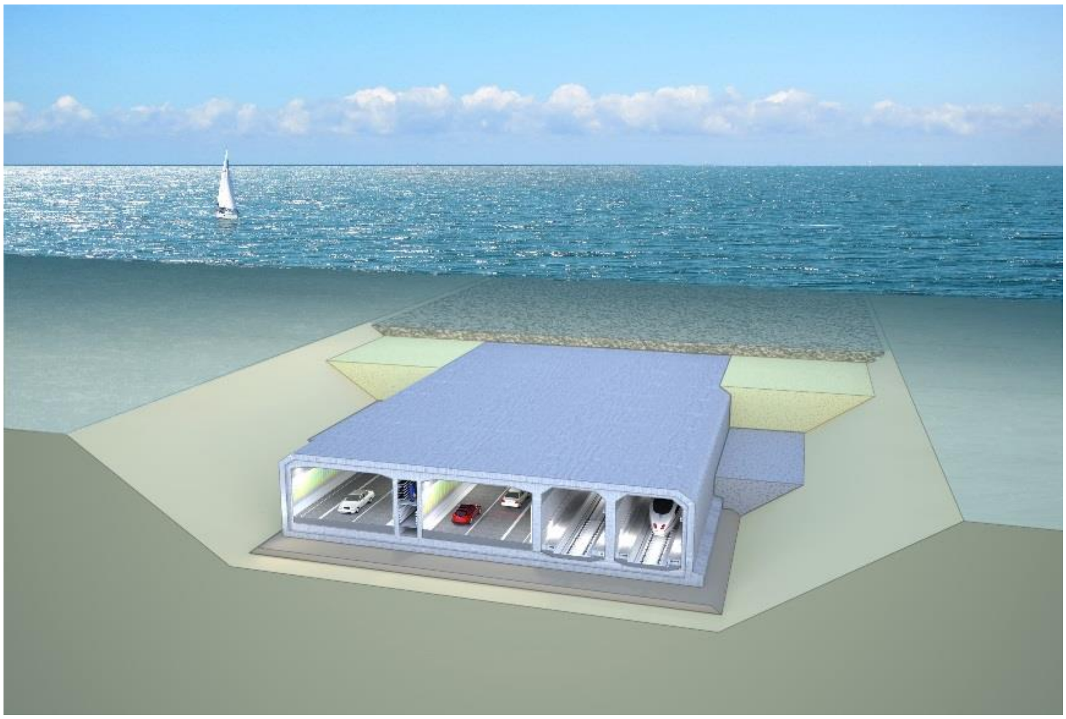
- dredging and Reclamation (D&R), covering the tunnel trench, artificial island, navigation channel realignment, peninsula at Kastup and environmental compensation dredging
- immersed Tube Tunnel and approaches at Kastrup and on Peberholm, including the mechanical and electrical systems in the tunnel
- high Bridge, a cable-stayed bridge over the Flinte channel
- east and west approach bridges

Later contracts covered coast-to-coast works (railway, communication systems, supervisory control and data acquisition [SCADA], and traffic control).

Here some differences with Storebælt can be noted. The works were divided into fewer packages. For example, on Storebælt the East Bridge had been divided into separate packages for superstructure and substructure, even though they were awarded to the same bidder. The West Bridge procurement similarly involved multiple packages. The owner was keen to not have too many contracts with multiple interfaces and for the contracts to be attractive to large international contractors.

Also, the owner set out with a much clearer idea of the preferred solution, making their strategic decisions pre-procurement. The bidders were not required to bid for multiple alternatives. The greater time that was taken between political approval and procurement and construction is worth noting.

Figure 5. Illustrative cross section of an immersed tube tunnel



The owner decided to divide the works into packages based on discipline rather than, say, geography. There was a debate on packaging the tunnel trench. Normally, the tunnel contractor would dredge the trench. And though there would typically not be a separate large-scale dredging contract for navigation channels, compensation dredging and the like, in this case the owner had an additional option. They decided to package the trench in the D&R contract despite the fact it created a potentially tricky interface with the tunnel contractor.

This kept all of the dredging and reclamation work in one contract, bringing large-scale economies. It also allowed the very onerous environmental constraints on dredging to be the focus of one contractor (see "Handling spill" below). The D&R contractor thus became responsible for delivering the prepared site to the tunnel contractor, and the tunnel contractor could focus on the concrete structure of the immersed tunnel. The tunnel contractor also placed in the trench the gravel bed that the concrete elements lay on. The owner recognised that it lay in the middle of this interface and managed it accordingly.

The owner spent a lot of time considering the best approach to the procurement and contract strategy. They knew that the decisions they made would determine the success of the project.

The procurement processes were as follows:

- Though the owner exercised strong oversight with their own technically and commercially experienced staff, the joint-venture consulting engineer produced the tender documents.
- The tender documents consisted of instructions to tenderers, the contract agreement, the general conditions of the contract, the scope of works, the reference conditions, the quality-

system requirements, the design requirements, the construction requirements, the administrative procedures and the illustrative design.

- Design risk would be transferred to the contractor. This was a fundamental change from Storebælt and a core belief of the owner in their strategy for the project (this is discussed in more detail below).
- Geotechnical risk was dealt with by using the reference conditions (bands and thresholds), with an associated compensation mechanism rather than being based on the traditional, and often contentious, foreseeability test. This was a change from Storebælt and is discussed in more detail below. Geotechnical information was made available.
- The tender documents did not include detailed design drawings and specifications but rather design requirements (including definition drawings) and an illustrative design. Detailed for-construction design and drawings were the contractor's responsibility.
- Bids were invited from pre-qualified joint-venture contractors. A pre-bid conference was held with a site visit. Bidders were able to ask questions during the tender period. Bids were received and opened by an opening committee.
- The owner evaluated the bids on a quality/price basis. Quality criteria covered the technical aspects and the management system proposals. In addition to the "raw" price, the financial assessment considered payment profiles and currency split. Any qualifications in the bids were assessed.
- The preferred bidder and most economically advantageous bid were identified. Meetings were held with the bidder to clarify any ambiguities and remove any qualifications in the bid.

The tender process was thus fairly conventional and not that dissimilar from Storebælt. What differed was the contract strategy behind the process. The founding principles of this new thinking on contract strategy are described below.

Design and build

Use of design and build contracting was fundamental to the owner's approach. The logic was to assign responsibility according to where competence lay and to integrate design and construction. Bespoke general conditions of contract were, however, developed in areas, and these incorporated FIDIC (International Federation of Consulting Engineers) provisions.

A key requirement of a design and build contract is to define the scope of what the contractor shall design and construct. A detailed unambiguous scope of works is essential. Given the multi-contract delivery of the fixed link, there were many interfaces between contractors. As regards scope, these represent potential disputes as to the boundary of each party's responsibility. The scope of works includes detailed interface descriptions of what was to be constructed and the timing.

A foundation of the contract strategy was that the contractor self-certify its design and construction work. The owner's quality system requirements defined the standards for the management system. Functional requirements rather than specification-type requirements (i.e. based on output not input) were used. The requirements that were produced by the technical teams were continually scrutinised and challenged.

The definition drawings defined only the fixed requirements for the design, with all other details being determined by the contractor. The fixed requirements were carefully considered to adequately define the owner's red lines but not unnecessarily constrict the contractor. So, for example, these defined the railway alignment but allowed the road alignment to be varied to reflect the contractor's tunnel element design, since tube wall thickness would be a factor in fixing the distance between rail and road alignments. The definition drawings also similarly defined the island outline, which was the outcome of extensive study of water flow in the strait, and height of the revetment, based on the owner's flood risk assessment. However, it left the design of the revetment to be engineered by the contractor.

In order to obtain approvals from the various authorities and to produce programmes and cost estimates, the owner had prepared an illustrative design. This was made available to bidders because it would assist them in preparing quality bids in the time available. Bidders could adopt elements of the illustrative design but importantly then took responsibility under their general design responsibility.

A new approach to geotechnical risk was taken using reference conditions. Rather than rely on the traditional foreseeability test for defining the boundary of geotechnical risk, the owner used a more objective method for defining the boundaries of each party's risk. The intention was that this would eliminate a regular source of dispute on construction projects. Various geotechnical parameters were defined and values were stated as the boundary between the contractor's and owner's risk. Because the bidders would rightly price this risk, the parameters and boundaries were carefully considered. The parameters used were those which would have most impact on the contractor's activities and which could be objectively measured. In setting the values, the aim was to choose a value that had a 90% chance of not being exceeded. Extensive geotechnical investigation was carried out, and one of the successful initiatives from Storebælt – the use of a geomodel – was again adopted.

Risk of adverse weather conditions and sea ice, which can have an impact on marine construction operations, were similarly dealt with using reference conditions.

As far as possible, bids were on a lump sum basis, and interim payments were made against payment milestones rather than being remeasured; this is a natural outcome of the design and build approach. The bidders were able to define the majority of the payment milestones and amounts based on their construction sequence. The owner defined some milestones and amounts (e.g. milestones for quality system documents and for completion milestones). Payments were indexed against a basket of indices. Payments could be split into different currencies, reflecting the international nature of the contractor joint ventures (exchange rate risk thus being an owner risk).

In the D&R contract, however, the majority of the dredging work was paid on a remeasured basis rather than using lump sum milestones simply because of the limitations of the accuracy of the seabed level survey (and the possibility that seabed levels could change). The bidders would have been unable to price volume risk accurately or would have priced it too high.

Handling spill

One of the most important aspects of the strategy of the D&R contract was how to deal with spill. This is sediment that is released into the water during dredging and can form a large plume, with a detrimental effect on marine biology. The project's onerous environmental permits limited spill to 5% of the dredging volume, much lower than the industry norm at that time (typically 25%).

The owner carried out a market engagement exercise during the preparation of the tender documents. In consultation with dredging industry representatives, the owner concluded that meeting the spill limit was achievable but would require much more powerful dredgers than would otherwise be required to meet the dredging rate. This is because large, powerful dredgers can excavate in a single pass what would take a smaller dredger a number of "bites", each of which disturb the ground and create spill. The spill allowance was broken down by time of year and area. The contract required the contractor to put in place a sophisticated real-time monitoring system, which fed back to the dredging operations such that dredgers would be moved between areas as spill limits per period were reached.

Restrictions on work sequencing were placed; reclamation was to be carried out within enclosed basins (fill could not be deposited in open water). This required the island revetments to be built before any fill was deposited. Thus, significant lengths of revetment needed to be built – 12km in the first year – before dredging of the tunnel trench could begin

Construction stage

The contractor's chosen methods involved extensive prefabrication, reducing in-situ construction. The bridge contractor prefabricated its foundation caissons and bridge piers at a purpose-built casting yard in Sweden near the site. The bridge deck (trusses) were fabricated in Spain, shipped by barge to the site and lifted into position. This was found to bring great benefit in reducing risk and improving quality because construction was carried out in controlled conditions rather than in the strait.

An immersed tube tunnel is by nature prefabricated and transported rather than constructed in situ. In this case, the owner's choice paved the way for successful construction.

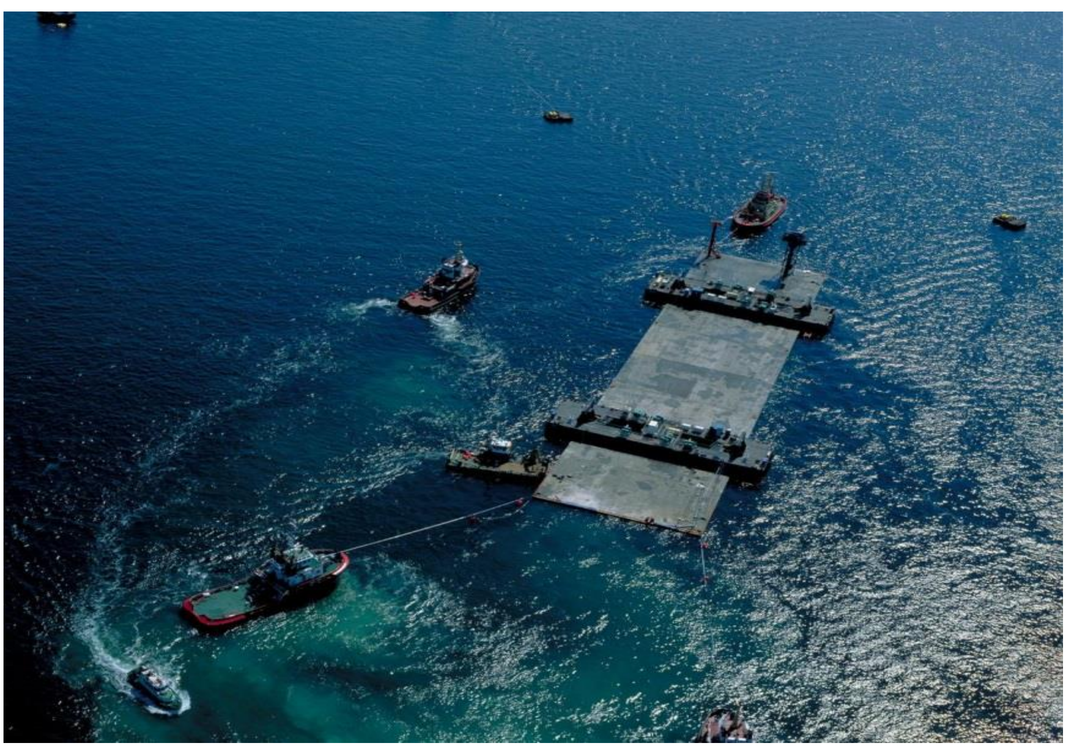
The contractors innovated in their methods, taking full advantage of the freedom they were being given and the opportunity to optimise and integrate design and method. The tunnel contractor produced all of the elements in a factory in Copenhagen's north harbour rather than in dry docks or within temporary dewatered cofferdams. This was the first time this method was used. Rebar was assembled and concrete poured within enclosed, controlled conditions. The elements were then slid into a basin for float-up, tow-out and immersion. The factory process was continually optimised such that production rates improved significantly over the course of the contract.

The D&R contractor similarly innovated, developing a method of constructing the revetments in open water from platforms and barges, using sophisticated survey and placing techniques to control alignment.

In the later stages, as the production rate improvements of the tunnel and bridge prefabrication methods became apparent, the owner assessed the programme. There was high confidence the link would be completed on schedule. The owner introduced a bonus scheme to help secure such completion. This was a side-agreement, and no changes to the contract or its risk allocation were made.

Figure 6. The dredger “Chicago” at work on the Øresund project

Figure 7. An element for the Øresund tunnel being towed out



Observations

The fixed link opened in July 2000. There were no outstanding disputes and the contractors were very positive about the owner's approach. There are of course many factors that contribute to a project being delivered successfully. For Øresund, the following were some of the most significant.

Figure 8. Production site for Øresund tunnel elements

The owner had clear objectives for what they wanted, but they were content for the detail to be filled out by those with greater competence. The philosophy was to assign responsibility according to where competence lay. The role of the owner is to lead the process not manage it in detail. The management philosophy was management through objectives, delegation and proactivity. Not only did the owner see this through internally, but they also did so with respect to their contractors. What's more, they maintained a clear view of their interest, which lay mainly in the finished product and meeting set functional requirements. They did not need to dictate how to get there. They exercised control through strategic intervention: review of design, systems and programmes and by audit.

The tender and contract documents were clear, and a lot of effort was made to produce high-quality documents.

The owner set out with a much clearer idea of the solution they wanted. This made it easier to produce high-quality documents.

The bidders were not required to bid for multiple alternatives and were better able to produce high-quality bids. The owner later reflected on the fact it had appointed the right contractors, and this contributed hugely to the success of the project.

The owner was clear that risk and ability to control that risk should go hand in hand. Risks which cannot be controlled or reasonably priced should be retained.

The mature approach to geotechnical risk and use of reference conditions proved beneficial. Given the massive scale of the geotechnical operations, a new approach was needed. Taking a pragmatic view that the owner provides the ground and the soils and therefore owns all geotechnical risk proved to be far-sighted. A contract can only ring-fence some of that risk to be taken and allowed for by the contractor. The boundary of that ring-fence should be objectively defined rather than being subjectively based on foreseeability. Because the boundary parameters were selected carefully and gave a realistic picture of the conditions, the concept signalled the owner's willingness to assume responsibility for the prevailing conditions. The owner chose values that could reasonably be locked into the contractor's price. And the bidders thus bid on the same basis. The owner also provided extensive geotechnical information such that the bidders could understand the prevailing conditions.

Using design and build proved to be one of the cornerstones of the project's success. A view endorsed by all of the contractors. At its simplest level it reduces construction cost and time by releasing the contractor from unnecessary constraints. It also removes the owner from an often tricky interface between designer and contractor. However, it also means the contractor must more fully understand the works.

Integrating design and construction creates opportunities to optimise that would not be available if design was complete before the contractor is appointed. The contractor can optimise not just costs but also speed, durability and quality and safety of construction. The owner gets better value for money.

The immersed tube tunnel demonstrates the appropriateness of design and build. The factory method depended on the design being customised to suit the method, while at the same time the method was developed with design optimisation in mind. The profound and detailed integration of design and method was particularly relevant due to the complex process of casting (large single pours), floating, transport, immersion and jointing that an element must undergo before it is in its final state. The methods at these stages drive the design as much as the owner's functional requirements for the permanent works. A consultant engineer working for the owner could never have arrived at the design that lay behind this method. A contractor on a traditional contract could never have proposed this method without an extensive redesign. The contractor seized the opportunity and delivered.

However, it is not enough to choose design and build – the strategy must then be executed. The owner must have extensive knowledge and experience, more so than for a traditional contract.

Design and build imposes a discipline to identify the overall objectives and to express them as a performance specification. Nevertheless, the owner must walk the line between functional requirement and specification. While many will argue the difference is clear, often it is a matter of choosing where to draw the line. As always the important thing is to know what your interest is and have a mature attitude to risk. To take an example, with regard to spill, the owner stipulated reclamation was to be carried out within enclosed basins, and fill could not be deposited in open water. This required the island revetments to be built before any fill was deposited, thus restricting the contractor's methodology. A functional requirement on paper would have meant simply placing the spill limit on the contractor and leaving them to decide. The owner understood that environmental risk could not simply be transferred in that way and took responsibility where they needed to.

Fehmarnbelt fixed link

In September 2008, the Danish and German Ministers for Transport signed the state treaty on the establishment of a fixed link across the Fehmarnbelt between the Danish island of Lolland and the German island of Fehmarn. In Denmark, the Danish parliament ratified the treaty through a planning act in April 2009. In Germany, the Bundestag and Bundesrat ratified the treaty in June and July 2009.

On the basis of the planning act, the Danish minister of transport appointed Sund and Bælt's wholly-owned subsidiary, Femern A/S, to be responsible for, among other things, the planning, feasibility studies and preparatory work for the construction of the coast-to-coast link.

From 2009, Femern A/S carried out a range of studies in the Fehmarnbelt and in Denmark and Germany, including studies of the land and marine environment, soil conditions and navigational safety issues. Various bridge and tunnel solutions for the fixed link were also studied. In November 2010, based upon the results of these studies, Femern A/S recommended an immersed tube tunnel as the preferred technical solution. The recommendation was accepted by the Danish cross-party political group that oversees the project (the Forligskredsen) in February 2011.

The immersed tunnel solution was taken forward for plan approval (permission) in Denmark and Germany. In October 2012, Femern A/S launched the procurement processes for four main civil works contracts. In April 2015, the Danish parliament passed the required construction act. The act authorises Femern A/S to construct and operate a fixed link across the Fehmarnbelt, together with the necessary landworks. The act contains the environmental approval for the project in Denmark, based on the EIA. It also authorises Femern A/S to finance the fixed link through loans.

In March 2016, the Forligskredsen gave Femern A/S the mandate to appoint the preferred bidders for the main civil works contracts, with the aim of then entering into conditional contracts (i.e. signed contracts but with construction postponed until the German plan approval is in place). In May 2016, Femern A/S signed such conditional contracts with the contractors.

As of the date of this paper, Femern A/S is awaiting the plan approval in Germany, which will allow construction of the coast-to-coast link to begin.

Figure 9. Cross section through the Fehmarnbelt tunnel

Procurement stage

For procurement, the civil engineering elements are divided into the following packages:

- dredging and reclamation, covering the tunnel trench and reclaimed areas on Lolland
- portals and ramps
- immersed tube tunnel north, covering the 9km length of tunnel from the Danish side
- immersed tube tunnel south, covering the 9km length of tunnel from the German side.

Other contracts cover coast-to-coast works (mechanical, electrical and control systems, and railway systems).

The similarity with Øresund is evident. The works were divided into a few large packages. The owner was again keen to not have too many contracts with multiple interfaces and for the contracts to be attractive to large international contractors. The owner did, though, choose to split the immersed tunnel contract into two. The reason was that the Fehmarn tunnel will be more than four times longer than the Øresund tunnel, and there was uncertainty as to whether a single contractor would have the capacity to take on a single package. In the event, both contracts were won by the same joint venture.

Again, the owner set out with a clear idea of the preferred solution; they made their strategic decisions pre-procurement. The bidders are not required to bid for multiple alternatives.

The owner once again opted to divide the works into packages based on discipline rather than, say, geography. So the same contractor is responsible for portals and ramps in both Denmark and Germany. And the tunnel trench is the responsibility of the dredging and reclamation contractor rather than the tunnel contractor.

The mechanical and electrical systems are being procured as a separate package rather than being included in the tunnel contract (and bridge contract) as they were on Øresund. This is more in line with the discipline-based packaging that the owner prefers. Given the length of the tunnel, the equipment and maintenance package is a major contract in its own right and can attract large international contractors.

The procurement process on Femernbælt has some similarities to Øresund:

- A joint-venture consulting engineer has produced the tender documents, though the owner exercises strong oversight with its own technically and commercially-experienced staff.
- The tender documents consist of instructions to tenderers, a contract agreement, the general conditions of contract, the scope of works, the reference conditions, the quality (management) system requirements, the design requirements (including definition drawings), the materials and construction requirements and the illustrative design. Bespoke general conditions of contract were developed, however, in certain areas, and these incorporated FIDIC provisions. A detailed unambiguous scope of works is provided, and it covers interfaces in detail.
- Design risk is transferred to the contractor.
- The illustrative design is based on the concept and “for-approvals” design prepared by the owner in the course of developing the project. As the bidders have a steep learning curve, from having no knowledge to submitting binding bids, providing an illustrative design makes the procurement process more efficient. The illustrative design helps bidders navigate and understand the written requirements. Bidders can adopt elements of the illustrative design as they choose. However,

this does not affect the allocation of design risk, which remains solely the contractor's responsibility.

- Geotechnical risk is dealt with by using reference conditions with an associated compensation mechanism. Geotechnical information was made available.
- Risk of adverse weather conditions and sea ice are dealt with using reference conditions.
- Bids are invited from pre-qualified joint-venture contractors. Pre-bid conferences are held with a site visit. Bidders are able to ask questions during the tender period.
- The owner evaluates the bids on a quality/price basis. Quality criteria cover the technical and the management system proposals. In addition to the "raw" price, the financial assessment takes in to account payment profiles. Any qualifications in the bids are assessed.
- The preferred bidder and most economically advantageous bid are identified. Meetings are held with the bidder to clarify any ambiguities and remove any qualifications in the bid.
- The contractor will self-certify its design and construction work.
- Functional requirements rather than specification-type requirements are used.
- As far as possible, bids are on a lump-sum basis, and interim payments are made against payment milestones rather than being remeasured.
- Spill is an important driving feature of the dredging and reclamation contract.

There were also some important differences, however. The procurement periods are much longer than either on Storebælt or Øresund. This reflects the increasing complexity of the procurement regulations and the risk of challenge. The owner needs a much more structured approach to procurement.

A multi-stage procurement process is used. Bidders prepare a technical bid, which is scrutinised by the owner (effectively being evaluated using the bid-evaluation criteria). The owner provides feedback, and the bidders then prepare a priced bid, which is similarly scrutinised.

The procurement process uses the competitive dialogue procedure as provided for in the Danish (and EU) procurement regulations. Under this, the owner and bidders have the opportunity to discuss the owner's requirements and the commercial aspects in a dialogue stage. The dialogue stage extends from the issue of the invitation to tender to a point determined by the owner, when the dialogue is closed and a call for final tender is issued.

The dialogue encompasses the technical bid and priced-bid stages and also a series of dialogue meetings around those bids. The aim of the dialogue is to identify and define the means best suited to satisfying the owners's needs. The owner runs a targeted dialogue, discussing only matters that may have a value-for-money implication. The owner's dialogue topics included: cost, risk, value, conditions of contract, technical requirements, programme and owner milestones, and interfaces.

Stage 3 included an intensive focus on cost, risk and value. Here, the owner took full advantage of the flexibility and close engagement allowed for by the competitive dialogue procedure within a still live competitive procurement environment. Under other procurement procedures, such intensive focus would be with the preferred bidder only. The owner was able to explore changes in risk allocation (and technical changes) on an equal, transparent basis with all bidders. The changes were targeted and the dialogue was kept narrow – with up to five bidders the right balance must be struck between creativity and control. The owner acknowledges the burden on the bidders in such an intensive exercise.

Table 2. The procurement timetable for the civil contracts is below.

Procurement timetable	Date
Industry day	March 2012
Introductory meeting	August 2013
Issue of the Stage 1 invitation documents (technical bids)	September 2013
Pre-bid conferences and site visit	November 2013
Stage 2, technical bids deadline	April 2014
Dialogue, phase 1	May – Sept. 2014
Issue of the Stage 2 invitation documents (technical and priced bids)	October 2014
Stage 2, technical and priced bid deadline	December 2014
Dialogue, phase 2	January – March 2015
Issue of the Stage 3 invitation documents (technical and priced bids)	April 2015
Stage 3, "Indicative bid" deadline (analogous to a "best and final offer" stage), technical and priced bid	May 2015
Close of dialogue and invitation to submit binding bids	August 2015
"Adjusted bid" (final and binding)	September 2015
Signing of civil works contracts	May 2016

Unsuccessful bidders are paid bid cost compensation. Here, the owner acknowledges that bid costs are significant on contracts of this scale and complexity. And the duration of and depth of engagement in the procurement process only adds to these costs. The compensation does not cover the whole bid costs, but the amounts are chosen to be meaningful. If bid cost is a factor for a bidder when deciding whether to pursue the opportunity, the compensation may tip the balance in favour of participating. This should help maximise competition for the owner.

Another difference is worth noting. As discussed previously, on Øresund the method for producing immersed tunnel elements was a contractor innovation. The owner focused on its functional requirements for the works and gave the contractor the freedom to decide how to deliver. On Fehmern, the owner has mandated the use of an Øresund-style production facility (on a much bigger scale, with more production lines). Here, the owner has strayed into an area which theoretically it would prefer not to.

There are various reasons for this departure from the owner's general approach to design and build contracting. First, it is certain this is the most efficient way to produce the elements. The large number that are needed mean the investment in the production facility is worthwhile. Indeed, this was proven in dialogue when no bidders pushed back on this requirement. Second, this method produces the standard of quality the owner wants. Third, and perhaps most notably, the owner needed to make decisions on production method as part of the environmental impact assessment for the project. The level of detail required by the rules around such an assessment meant the owner selected the area in Denmark near the site (Rødby) as the location for producing the elements and also selected the method.

The above shows the sophisticated owner needs to be flexible in their approach and be prepared to change their position and, more importantly, then manage the risk this brings.

Another change is that the dredging and reclamation contract includes an incentive mechanism to help reduce the owner's costs at the interface between the dredging and tunnel contractors. The dredging contractor dredges the tunnel trench; the tunnel contractor lays a gravel bed, places the element and then backfills the sides of the trench. The owner carries the risk on the gravel bed and backfill volume because the tunnel contractor cannot control this. The mechanism incentivises the dredging contractor to minimise the gravel bed and backfill volumes.

An incentive mechanism is also included on spill volume. This is a simple financial incentive mechanism to provide some gain to balance the contractual "pain" if the limits are exceeded. Regardless of the fact the contractor must be below the spill limit, the owner recognises that environmental risk like this is never fully transferred and added leverage on the contractor may be useful.

It is also worth noting the principle of self-certification has been taken to another level, influenced by the introduction of Eurocodes. Different parts of the structures are classified under "consequence classes", and the design of parts in the highest classification is subject to independent verification from a third party. These parts include the main structure of the tunnel elements and the steel bulkheads that must temporarily resist large hydrostatic forces. To be clear, this check is not carried out by the owner's technical adviser. It is carried out by a third-party technical adviser employed by the contractor, who is independent from the contractor's main design consultant.

Observations

For the Femernbælt fixed link, the owner has been able to apply many of the principles that contributed to the success of the Øresund project.

However, they have not been able to remain complacent and have had to adapt to the new procurement regulation regime and to the ever-more stringent environmental requirements. In short, they have made sure their choices are appropriate to this project's risks and opportunities.

Figure 10. Visualisation of the Fehmarnbaelt tunnel portal on the island of Lolland

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Appendix 1. Research questions and outputs

Introduction: Getting the basics right

What are the economic characteristics of infrastructure? What is infrastructure and what are operations? What are the models of private participation in infrastructure and through which significant private investment actually takes place?	Makovšek, D. (2018), "What is Private Investment in Transport Infrastructure and Why is it Difficult?", Working Group Paper, International Transport Forum, Paris (forthcoming).
Can private investment improve productive efficiency? Improve project selection? Close the infrastructure funding gap? Have other positive effects when it is private?	Makovšek, D. (2018), "The Role of Private Investment in Transport Infrastructure", Working Group Paper, International Transport Forum, Paris (forthcoming).
What have the private investment trends in transport infrastructure been over the last 20 years? How much of that was foreign private investment?	Mistura, F. (2018), "Quantifying Private and Foreign Investment in Transport Infrastructure", Working Group Paper, International Transport Forum, Paris (forthcoming).

Defining the challenge: How uncertainty in contracts matters

How does uncertainty affect risk pricing? Beyond investors, do suppliers in PPPs also have issues with risk pricing? How does its transfer to the private sector affect competition? What does uncertainty mean for the public vs. private cost of financing?	Makovšek, D. and Moszoro, M. (2018), "Risk pricing inefficiency in public–private partnerships", *Transport Reviews*, *38*(3), 298-321.
Is uncertainty also an issue in long-term services/operations contracts?	Beck et al. (2018), "Uncertainty in Long-term Service Contracts: Franchising Rail Transport Operations", Working Group Paper, International Transport Forum, Paris (forthcoming).
What is the competition for large transport infrastructure projects in the EU Market? Is there a difference between traditional procurement and PPPs?	Roumboutsos, A. (2018)," Competition for Infrastructure Projects: Traditional Procurement and PPPs in Europe", Working Group Paper, International Transport Forum, Paris (forthcoming).

Addressing uncertainty for suppliers: the construction phase as example

Adversarial vs. collaborative procurement – is collaborative contracting the future?	Eriksson et al. (2018), "Collaborative Infrastructure Procurement in Sweden and the Netherlands", Working Group Paper, International Transport Forum, Paris (forthcoming).
What lessons in dealing with risk and uncertainty were learnt in Danish mega projects from Storebaelt to Femernbaelt?	Vincentsen, L. and Andersson, K. S. (2018), "Risk Allocation in Mega-Projects in Denmark", Working Group Paper, International Transport Forum, Paris (forthcoming).
What can governments do in the short run to reduce inefficient pricing of risk by construction contractors?	Kennedy et al. (2018), "Risk Pricing in Infrastructure Delivery: Making Procurement Less Costly", Working Group Paper, International Transport Forum, Paris (forthcoming).

Addressing uncertainty in long-term contracts in the absence of continuous pressure for efficiency

What is the public sector organisational counterfactual on which private investment should seek to improve?	Holm, K.V. and Nielsen, T.H. (2018), "The Danish State Guarantee Model for Infrastructure Investment", Working Group Paper, International Transport Forum, Paris (forthcoming).

Partial fixes to the Private-Public Partnership approach

How would an organisational structure consisting of PPPs come close to a network-wide management approach? What benefits would it yield?	Vasallo, J. (2018), "Public-Private Partnerships in Transport: Unbundling Prices from User Charges", Working Group Paper, International Transport Forum, Paris (forthcoming).
Should the public or the private side bear the cost of long-term uncertainty? How could we design a PPP contract to avoid hold-up due to incomplete contracts?	Engel et al., (2018), "Dealing with the Obsolescence of Transport Infrastructure in Public-Private Partnerships", Working Group Paper, International Transport Forum, Paris (forthcoming).

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What basic considerations underlie the choice between a PPP and RAB approach?	Hasselgren, B. (2018), "Risk allocation in Public-Private Partnerships and the Regulatory Asset Base Model", Working Group Paper, International Transport Forum, Paris (forthcoming).
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From the investors' point of view, does a RAB need to be fully reliant on user-charging?	Francis, R. and Elliot, D. (2018), "Infrastructure Funding: Does it Matter Where the Money Comes From?", Working Group Paper, International Transport Forum, Paris (forthcoming).
Incentive regulation can also yield perverse incentives. Can the capex bias be managed?	Smith et al. (2018), "Capex Bias and Adverse Incentives in Incentive Regulation: Issues and Solutions", Working Group Paper, International Transport Forum, Paris (forthcoming).
Does it make sense to pursue hybrid solutions between PPP and RAB?	Zhivov, N. (2018), "The Thames Tideway Tunnel: A Hybrid Approach to Infrastructure Delivery", Working Group Paper, International Transport Forum, Paris (forthcoming).

Uncertainty and private investment mobilisation in transport infrastructure

What lessons can we draw from recent attempts to mobilise private investment in infrastructure in the aftermath of the global financial crisis?	Makovšek, D. (2018), "Mobilising Private Investment in Infrastructure: Investment De-Risking and Uncertainty", Working Group Paper, International Transport Forum, Paris (forthcoming).
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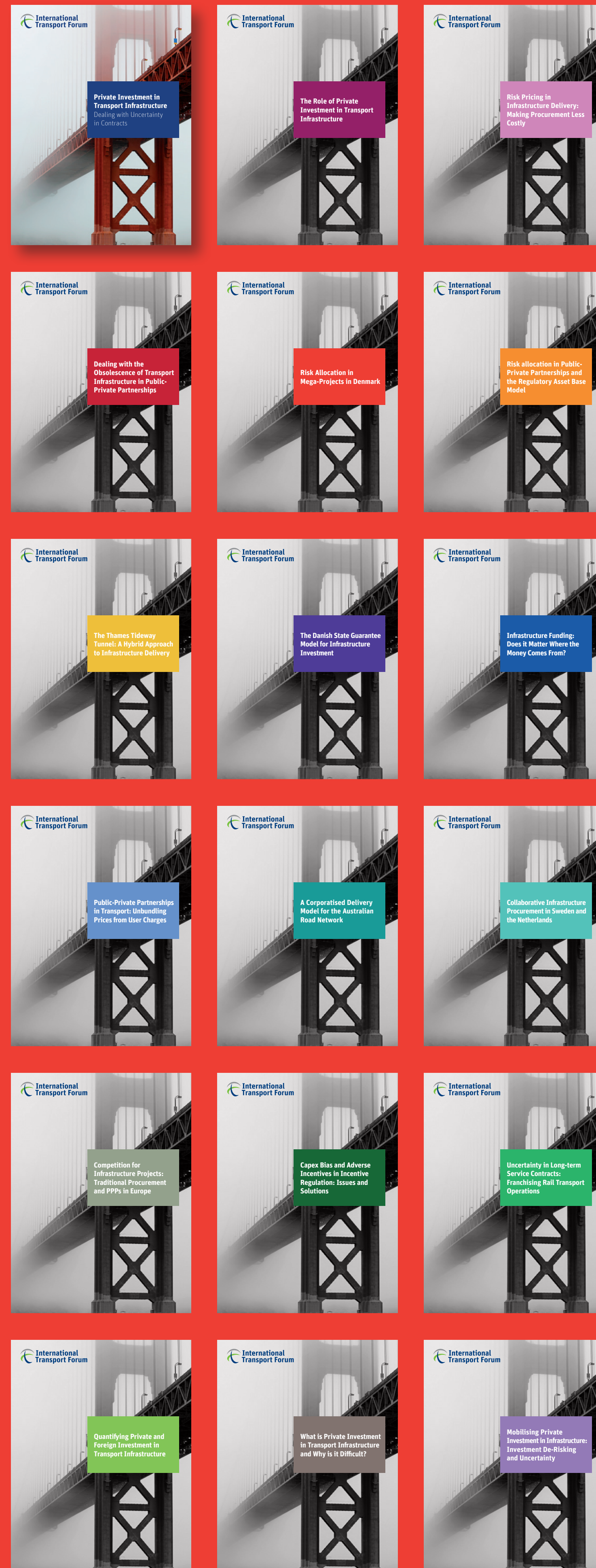
Risk Allocation in Mega-Projects in Denmark

This paper uses three Danish-Swedish-German transport infrastructure mega-projects - the Storebælt, Øresund and Femern Belt links - as a case study to examine risk allocation between owners and contractors. It highlights the evolution of the approach to risk allocation over time and how the projects deal with uncertainty. The paper is part of a series of 19 papers and a synthesis report produced by the International Transport Forum's Working Group on Private Investment in Transport Infrastructure.



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