Risk Governance for Procurement in Future Fuels – Interim Report 1

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Risk Governance for Procurement in Future Fuels

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Project Information	
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Research Program	Research Program 2 – Social Acceptance, Public Safety and Security of Supply
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Description	This interim report covers the literature review phase of the project. It details known procurement risks and lessons learned from procurement failures. Together with stakeholder interviews, it provides the basis for the next phase of the project – developing a risk governance framework and risk mitigation recommendations.
Research Provider	RMIT University
Project Leader and Team	Jan Hayes, Nader Naderpajouh, Rita Zhang, Yen Pham, Ron Wakefield, Priyanka Erasmus (all RMIT)
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Summary of report

Excellence in governance of procurement risk is a key success factor for the gas industry in working to deliver decarbonised energy.

Procurement is a complex process and while the gas industry has done well in this area overall, there is still room for improvement and value in reflecting on particular procurement issues posed by future fuels projects linked to hydrogen and biogas (and other possible fuels). This project aims to develop an understanding of critical gateway points in the procurement process and the practices that can be implemented to improve risk governance in the gas pipeline sector. Such understanding will encourage the diligent and established application of risk mitigation measures in the procurement practices implemented for future fuels infrastructure and technology development.

Procurement is a series of planning, organizing and coordinating processes to obtain goods and services from an external source by an organization (Turban et al., 2017).

In this project we consider that ***procurement fails*** when failures in procurement planning (scoping or contracting); specification, purchasing, manufacturing, or delivery of goods or services result in a project failing to meet stakeholder objectives (both short and long term).

In this first interim report, the results of various literature review activities are described and summarised, specifically:

Known procurement risk sources and consequences

Academic and grey literature sources have been reviewed to develop a taxonomy of procurement risks. Four main risk categories have been identified. Each includes a range of risk sources as shown in Table 1. These are generic sources of procurement risk as the literature covers a wide range of industries and projects.

Table 1. Key procurement risk sources in supply chain identified from the literature

Risk category	Risk source
Supply chain coordination & management	Contractual terms & conditions
	Scope & baseline specification
	Demand & scope changes
	Supply chain configuration
	Planning & forecasting
	Communication
	Logistics
	Cash flow management
	Inventory
	Corporate social responsibility
	Experience & expertise
	Risk management
	Quality assurance / Quality control
Supplier	Performance & operations
	Financial stability
	Supplier behaviour
	Infrastructure & resources
	Supplier environment & market

	Supplier experience & expertise Sub-suppliers
External environment	Law & regulations Standards & codes Economic Political & governmental Natural events Environment, health & safety Sociocultural
Cooperation & trust	Trust issues Culture issues Conflict

Procurement failure can have a range of consequences as identified in Table 2.

Table 2. Consequences from failures in procurement risk management

Consequence category	Example of consequence
Economic	Extra capital costs Extra operating costs Project delay Contract breach External costs Poor interface with existing operations
Environmental	Pollution (air, land, water) Reduced sustainability Land degradation Impact on flora/fauna/wildlife habitats Noise Odour
Social	Worker safety Public safety Modern slavery Workplace/public health Culture/heritage damage
Legal	Criminal charges Licences revoked
Reputational	Reputational loss or damage

Further details are given in Section 3.1.

Lessons learned from past procurement failures

Nineteen significant procurement failures have been identified where significant information on causes is available in the public domain. The failures are drawn from a range of sectors/industries including building, infrastructure, aerospace, aviation, transport, maritime, energy generation, oil industry and chemicals processing.

The total 73 sources of risk and associated practice lessons from the nineteen procurement failures have been classified according to the risk categories and sources above. Fifty-five relate to supply chain coordination and management, five causal factors were directly linked to suppliers and five demonstrated a connection to external risk factors. Trust and cooperation issues were flagged as contributing causes on eight of the nineteen incidents.

Looking more closely at risk sources shows that ten of the nineteen incidents were partly caused by issues with supply chain configuration. In most cases, this relates to selection of a supplier that was not suited to provide the goods/services required. In some cases, it was because there was no effective prequalification system in place. In other cases, it was because a marginal supplier was chosen on the basis of low cost, but no additional measures were put in place to ensure that a suitable quality was maintained. Another supply chain configuration issue common to several failure cases is a poor link from procurement activities into ongoing operations so failures occurred at the end of the project when this gap was uncovered. Other interface co-ordination issues arose in three cases – in one case the supply chain was configured so that oversight functions reported to those that their activities were meant to check meaning that no action was taken when problems arose and in the other two cases there was no effective construction management contractor, so no-one was responsible for managing the interfaces between multiple smaller pieces of work.

Quality assurance (QA) and quality control issues also contributed to ten of the nineteen incidents. Poor testing (usually testing conditions not matching service conditions), fraudulent test certificates, product substitution, gaps in QA scopes and poor links from adverse QA results back into project decision making are the key themes.

Further details are given in Section 3.2.

Published procurement guidance

The third source of data on procurement risks and how to management them drawn on in this report is public domain guidance material on best practice in risk management for major projects. Seven sets of guidance material have been reviewed:

- The UK Government Construction Playbook
- In Plain Sight (report by the UK Institution of Civil Engineers)
- Victorian government guidance on procurement
- Victorian Civil Construction industry best practice guide for tendering and contract management
- Infrastructure NSW framework for establishing effective project procurement
- Austroads and the Australian Procurement and Construction Council procurement guide
- World Bank policy research working paper on improving procurement outcomes

Common themes are all related to planning for procurement such as contractor/supplier prequalification, using the right contracting model, early contractor engagement, allocating risk to the party best able to manage it and sharing of risks and rewards.

Overall, the data collected so far provides a rich picture on procurement risks, how they arise and how they might be prevented or mitigated but the information is generic. In the next stage of the project, gas sector procurement specialists from along the supply chain will be interviewed to draw on their experience of risks and risk management within the gas sector. A further interim report including that work is due for release in June 2022.

Further details are given in Section 3.3.

Other sources of relevant information

While conducting the literature review and speaking to stakeholders, we have come across many excellent sources of information related to management of projects, project risk governance and supply chain management. For the purposes of this interim report, they are summarised in Section 3.4.

Most of the work done to date provides input into later stages of the project but procurement failures cases may be directly useful to industry in their current form. Experienced professionals learn best by considering cases and the report provides nineteen examples of procurement failures that an provide the basis for discussion to reflect on current procurement practices and the potential for the same weaknesses to be present in any specific set of procurement practices.

The next stage of the project (which is already underway) is to add to the understanding of procurement risks, particularly in the context of future fuels, by conducting stakeholder interviews. The focus of the research is also shifting from an understanding of relevant risks to the practices that need to be put in place to control them.

1 Introduction

The development of a new future fuels sector in Australia represents a major opportunity for the gas industry. The reputation of this emerging sector will depend on the successful execution of early projects as any major failures will be a reflection on the sector as a whole. For all major infrastructure projects, one key issue is successful supply chain management. This research aims to support risk management in procurement in the context of future fuels. Specifically, the research aims to reduce the risk of unplanned outcomes caused by failures in procurement practices within the supply chain and support the emerging future fuels industry to meet societal expectations for delivery of safe and reliable new infrastructure and technologies.

Despite the cruciality of procurement procedures and supply chain management in the successful execution of infrastructure projects, there have been many examples of procurement failures leading to unplanned adverse outcomes including:

- NSW trains too wide for tunnels (2018)
- Grenfell Tower fire (2017) and other building sector incidents
- South Korea nuclear reactor shutdowns (2013)
- HMAS Westralia (1998)
- Canberra Hospital Implosion (1997)

The gas industry has not been immune from such incidents although specifics are often not readily available to share due to commercial/legal issues.

Cost and schedule implications of late delivery of procured items, potential safety risks as a result of counterfeit items, and failures to meet expectations for levels of service provided are among the common issues. Widening of NSW railway tunnels to allow for incorrectly specified new trains cost the NSW government $75 million[1]. The cost of replacing off-specification flammable cladding in Victoria is estimated to be between $250 million and $1.6 billion[2].

Failures of materials, equipment or services through ineffective supply chain risk management represent threats to the successful development of the emerging hydrogen and biogas future fuels industry. In addition to the potential for major cost and schedule blowouts, failures on any early project in this new industry could cause significant reputation damage and so adversely impact the development of the entire sector. Research into effective mitigation of such threats is warranted to ensure that societal expectations for public safety are met and that the reputation of both organisations and new technologies are protected.

With these factors in mind, research questions addressed by this project are:

- Why have past significant procurement failures in the gas industry and elsewhere occurred? What can be learned from them?
- What are the risks associated with the procurement process in the gas industry and what risk governance practices can be used to prevent the recurrence of procurement failures in the context of future fuels?
- What does a robust procurement risk governance framework look like in a future fuels environment?

The project involves four main tasks:

1. Literature review
2. Study current procurement practices
3. Develop risk governance framework
4. Develop risk mitigation recommendations

[1] https://www.smh.com.au/national/nsw/blue-mountains-rail-line-gets-75-million-upgrade-20181218-p50mxn.html
[2] https://theconversation.com/flammable-cladding-costs-could-approach-billions-for-building-owners-if-authorities-dither-118121

In the first task of the project, a review of academic, grey, government and industry literature on procurement risks and associated failures of engineering and infrastructure projects has been conducted. These include identification and analysis of risks on the supply side and the supply chain coordination and management process, risks from the external environment, and risks related to behaviour and cooperation. Lessons learned from procurement failures in engineering and infrastructure incidents have been discussed. Finally, documented procurement practices and guidance on best practice in procurement risk governance have also been highlighted.

The focus of the project is now shifted to Task 2 where interviews with key stakeholders from the gas and pipeline sector have commenced, followed by preparation of process maps on procurement practices. The next interim report will be shared with industry advisors by June 2022.

The overall outcome from the project will be an understanding of critical gateway points in the procurement process and the practices that can be implemented to improve risk governance in the gas pipeline sector. Such understanding will encourage the diligent and established application of risk mitigation measures in the procurement practices implemented for future fuels infrastructure and technology development.

2 Theoretical foundations

2.1 Definitions

The project is grounded in the idea of how best to manage the risk associated with procurement failure, so it is important to define some key terms.

Procurement is a series of planning, organizing and coordinating processes to obtain goods and services from an external source by an organization (Turban et al., 2017).

In this project we consider that ***procurement fails*** when failures in procurement planning (scoping or contracting); specification, purchasing, manufacturing, or delivery of goods or services result in a project failing to meet stakeholder objectives (both short and long term).

This implies that failures can occur at various stages along the supply chain. It should also be noted that stakeholders can have differing objectives so views on whether, and the extent to which, failure has occurred is at least partly a social construction.

The project draws on ISO 31000 for language related to risk. ***Risk*** is defined in the standard as the effect of uncertainty on objectives, noting that an effect is a deviation from the expected (ISO, 2018). In ISO 31000, effects can be positive or negative but in this project we focus on negative effects.

In the language of ISO 31000, objects, events or circumstances that have the potential to give rise to risk are called ***risk sources***. An outcome impacting objectives is a ***consequence***, noting that consequences can escalate due to cascading and cumulative effects.

2.2 Organisational failures

Many of the risk sources in procurement are organisational so it is important to set out the way in which the work conceptualises organisational failure as opposed to human error.

In recent years, the extensive research literature has examined both the prevalence and causality of major failures within complex socio-technical systems (for example, see (Vaughan, 1996)). These studies demonstrate that disasters are as much an outcome of social relations as they are a result of technical failings and so these types of disasters can most usefully be thought of as organisational accidents. Organisational accidents are events that occur within complex modern technologies, such as nuclear power stations, commercial aviation, and oil and gas facilities and have multiple causes involving many people working in different areas and at different levels. Analysing an incident in this framework involves a search for not only technical causes, but also causes related to systems of work and the actions of people throughout the organisation.

One of the most well-known models of organisational accidents is James Reason's Swiss Cheese Model of Accident Causation shown in Figure 1 (Reason, 1997). In this way of thinking about accidents, there is a range of defences in place that are functionally designed to prevent any given hazard from leading to a loss of some kind (such as an accident). In practice, these defences are imperfect (like holes in Swiss cheese). The various hardware and procedural measures in place ensure that failure of any individual measure is not catastrophic. An accident occurs when the holes in the cheese line up and provide an accident trajectory through all of the defences.

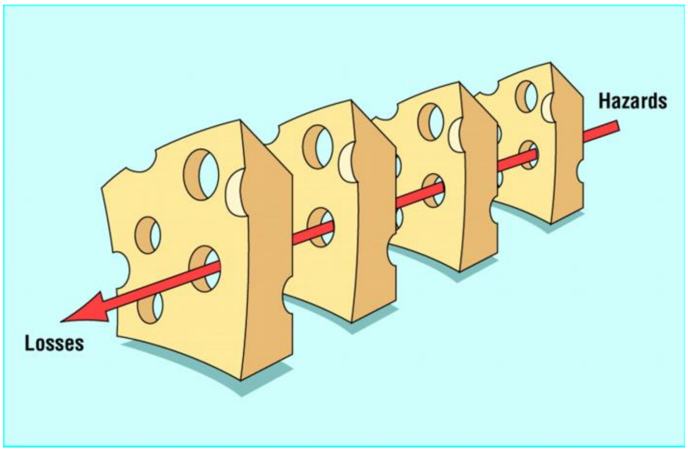

Figure 1. Swiss cheese model

In this model, the "holes" in the cheese have two interesting features. First, they may be due to active failures, such as the mistakes or non-compliant behaviour of frontline operators, or they may be due to latent failures. Latent failures are weaknesses in the system that do not, of themselves, initiate an accident, but they fail to prevent an accident when an active failure calls them into play on a given day. Problems arise when latent failures in the system accumulate – maintenance is not done, records are not kept, audits are not done. The consequence of a small active failure can then be catastrophic as the protective systems fail to function as expected.

The second feature of the holes in the Swiss cheese is that they are a function of the organisation itself. In this model of accident causation, operator actions in the field are linked to workplace factors, such as competency, rostering, control room design, task design etc., and these issues are linked to organisational factors such as budgets, safety priorities, management styles etc. In this way of thinking about safety defences, the performance of all components in the system is interlinked.

While Reason's model was developed with physical disasters in mind, this type of thinking about failure applies equally to other types of objectives such as meeting schedule and cost in a project environment. The aspect of Reason's model that is of relevance for this stage of the research project is the 'holes' in the Swiss cheese that represents vulnerabilities of the system. Moving further into risk the management process, we also adopt the elements of the Bowtie model (Figure 2) as a theoretical framework for this project. A bow tie is a diagrammatic representation of a specific hazardous event ("Top event"), the causes and consequences of the event, plus all the controls in place to prevent, mitigate and recover from the event ("Barriers of controls") (Bice & Hayes, 2009). The threats or events/conditions that potentially cause the Top Event along with the current risk controls (or reduction measures) are identified first. The consequences of the Top Event which are possible outcomes that could occur are also realised. Once the consequences are developed, the next step is to identify recovery measures that can stop, limit or recover from the impact arising from the Top Event. In this report, known procurement risks, associated failures and potential consequences are analysed and at the later stage of the project, we will move further into understanding barriers of controls to reduce the risk of failure.

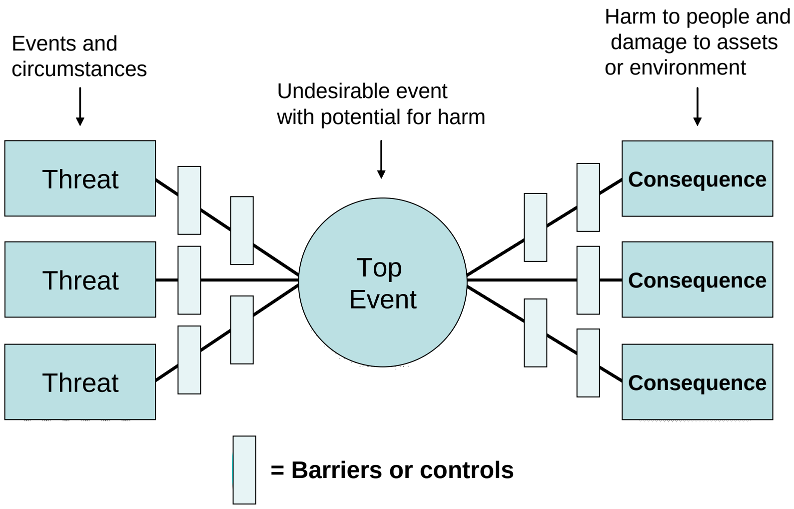

Figure 2. Generic Bow Tie Diagram[3]

3 Literature review

A literature review has been completed to identify known procurement risk sources and consequences, documented procurement practices being implemented for major public sector infrastructure projects, and guidance on best practice in procurement for risk governance. The following types of documents have been searched in this literature review:

- New or revised government and industry guidance material,
- Academic and grey publications, and
- Incident investigation or inquiry reports.

The review also focuses on past incidents and proposed best practice for procurement risk governance. In each case study, we have highlighted procurement issues and lessons learned from those failures.

3.1 Known procurement risk sources and consequences

All procurement is exposed to many kinds of risks and uncertainties in price, lead time, demand (Hong et al., 2018) so managing risks is an integral part of procurement governance and planning. A risk management plan at the project planning should consider potential risks at all stages of the procurement process. The objective of this process is not only to early detect potential issues and reduce negative outcomes but to identify opportunities to improve performance, enable more efficient use of resources and increased probability of success.

The first part of the literature review within this project is to identify and categorize known procurement risk sources and consequences. Current literature has shown a variety of risk structuring and classification systems with little uniformity among different approaches (Edwards et al., 2020; Rudolf & Spinler, 2018). It may not be feasible to have a comprehensive identification and description of all potential risks because of the dependence of risk situation on specific contexts (Rudolf & Spinler, 2018) and the infinite number of potential risks.

A taxonomy of procurement risk sources has been adapted from the taxonomy of supply chain risks in large-scale engineering and construction projects developed in Rudolf and Spinler (2018). Several authors have attempted to differentiate procurement risk from supply chain risk as the former has been viewed as more about the supply discontinuity and the agreement between the supplier and the purchasing organizations (Hong et al., 2018). For the purposes of this project, we have assumed that procurement management and supply chain

[3] Adapted from Visser, J. P. (1998) Developments in HSE Management in Oil and Gas Exploration and Production, in *Safety Management: The Challenge of Change* (Eds, Hale, A. and Baram, M.) Pergamon, Oxford.

management are synonymous and so we have drawn on both literatures in developing what follows. Table 3 exhibits an overview of the potential procurement risk categories and risk sources. There are four main risk categories including (1) supply chain coordination and management; (2) supplier; (3) external environment and (4) cooperation and trust. Risks in the supply chain coordination and management category are internal to a purchasing firm, whereas supplier risk sources are external to the firm but within the internal supply chain networks. Although external environment risks originate outside the supply chain, they might adversely impact the networks. We also look at risks to cooperation and trust which have been considered as highly important for large-scale projects (Cox et al., 2006). The following sections present details on possible risks in each category.

Table 3. Key procurement risk sources in supply chain identified from the literature

Risk category	Risk source
Supply chain coordination & management	Contractual terms & conditions Scope & baseline specification Demand & scope changes Supply chain configuration Planning & forecasting Communication Logistics Cash flow management Inventory Corporate social responsibility Experience & expertise Risk management Quality assurance / Quality control
Supplier	Performance & operations Financial stability Supplier behaviour Infrastructure & resources Supplier environment & market Supplier experience & expertise Sub-suppliers
External environment	Law & regulations Standards & codes Economic Political & governmental Natural events Environment, health & safety Sociocultural
Cooperation & trust	Trust issues Culture issues Conflict

We are aware that there is some overlap between these risk sources e.g., several of the external environmental factors are causes of risks in the supplier and supply chain coordination and management category. At this stage of the project, all risk sources have been retained so that none of the rich picture of the literature is lost. As the project progresses, this material will be rationalised.

3.1.1 Supply chain coordination and management

Risks within the supply chain coordination and management category are defined as failures of the processes of specifying what is required by the customers and/or end-users, as well as selecting and managing suppliers, and coordinating and managing the supply chain to meet the customer demand (Table 4). Stakeholders involved in the supply chain coordination and management include purchasing personnel, construction managers, engineering specialists and consultants, company system safety and logistic specialists, and third-party verifiers such as certification and quality specialists.

Table 4. Risks related to supply chain coordination and management

Risk source	Examples of risk events
Contractual terms & conditions	Incomplete contractual baseline (e.g., due to unfixed scope, unclear specifications, poor designs) Lack of clarity in contract requirements Reluctance of suppliers to accept contractual changes Contractual disputes or dispute settlements
Scope & baseline specifications	Misspecification, poorly developed specification Poorly defined scope Scope modifications due to volatile and changing customer expectations and external influences
Demand & scope changes	Increasing demand volatility and uncertainty Mismatch between projections and actual demand
Supply chain configuration	Inadequate selection and evaluation of suppliers Insufficient estimation of time and costs Overreliance on limited number of suppliers or on certain locations
Planning & forecasting	Incorrect cost estimates or schedules Inadequate preplanning studies Planning fallacy (Delusion optimism)
Communication	Inadequate communication in knowledge transfer, change management, partnership performance and integration of material and information flows Untimely, incorrectly information sharing Inter-agency relationships poorly function Inadequate IT system
Logistics	Disruptions due to custom procedures, import duties and embargo Inefficient logistic and material delivery processes
Cash flow management	Inaccurate cash flow forecasts Improper cost control measures
Inventory	Over-ordering, excessive or mismatched inventory
Corporate social responsibility	Legal, ethical, social, environmental responsibilities through the supply chain (e.g., child labour, modern slavery, environmental protection etc.)

Risk source	Examples of risk events
Experience & expertise	Different levels of understanding of supply chain aspects Lack of information in procurement for unique or unconventional goods or services Lack of competencies of practitioners (inadequate CPD and CPC)
Risk management	Risks not identified and so not adequately managed Lack of monitoring of risk controls
Quality assurance / Quality control	Unclear responsibility of practitioners involved Inconsistent or poor-quality supervision and oversight Incorrect or fraudulent product certification, especially with imported products Lack of checking or audit mechanisms for inspection activities

Contractual terms and conditions have been identified as one of the critical supply chain risk sources in the literature as poorly formulated contractual terms and conditions might lead to expensive changes during project execution (Rudolf & Spinler, 2018). One of the main reasons for contractual changes is that large-scale projects often have an incomplete contractual baseline, i.e., the basis on which the contract is to be prepared is not completely understood. Inadequate consideration of special local requirements and conditions, unclear technical specifications, and poor designs are some of the primary causes of a scope of work that is not fully fixed, and this consequently leads to an incomplete contractual baseline (Rudolf & Spinler, 2018). Volatile and changing customer expectations and external influences are other factors that lead to changes in ***scope and baseline specifications*** in large-scale projects. Misspecification as well as poorly developed specifications or poorly defined scope might result in extra project budget and significant delays. In many such cases, contractual agreements are vague on objectives (Tirole, 1999) or complex without sufficient clarity in performance requirements, resulting in ambiguities of the requirements and so misunderstanding. These factors may subsequently lead to major contractual amendments and time and cost overruns (Parliament of Victoria, 2012).

The introduction of new laws and regulations or revised standards and codes might also drive changes in contractual terms and conditions. Suppliers are not always adaptive or willing to adjust terms if conditions change due to related costs. There is also a possibility of contractual disputes between parties on project costs and priorities as a result of poorly defined performance requirements (Victorian Auditor-General's Office, 2015), and issues with dispute settlements (Khallaf et al., 2018). These all can cause delays in achieving final agreements.

While there is a tendency that companies likely focus on the supply side of their operations, risk factors on the customer side, including ***demand and scope changes***, should also be given consideration. Increasing customer demand volatility and uncertainty are significant factors that might affect a firm's operation and revenues. Mismatches between forecasts of customer demand and actual demand can lead to costly shortages, obsolescence and inefficient capacity utilization (Wagner & Bode, 2009).

A visible example is the impact of the current Covid-19 crisis. Soon after the Covid-19 epidemic became a pandemic in March 2020, the oil price collapsed owing to a decline in demand[4]. A massive increase in demand for medical equipment at almost the same time followed by huge demands for goods and services have distorted global supply chains. Such a sudden shift in customer demand coupled with production outages due to lockdown has caused a supply crisis with unavoidable delays in production and distribution.

Problems can arise in the ***configuration of the supply chain*** with failures in selecting and evaluating suppliers. These include the inadequate competency and quality of contractors and subcontracts (Larsson et al., 2014) which might lead to contract deliverables not meeting expectations and project schedule and costs being affected. Just-in-time methods and lean inventory model whereby managers reduce costs by limiting the number of suppliers and keeping inventories low can increase risk levels due to the lack of buffer capacity (Fiksel et al.,

[4] https://www.raconteur.net/supply-chain/black-swan-attack-can-world-trade-take-any-more-trauma/

2015). Over-reliance on products or services to be provided by one supplier or on certain locations might be a threat as the production and distribution continuity depends not only on that supplier but also on the external factors. For example, within a week after the 2011 Japan Tsunami, General Motors Corp. had to temporarily shut down its plants in Colorado and Louisiana due to disruptions in component supply from Japan (Fiksel et al., 2015). The recent Suez Canal crisis has demonstrated the global impact of a single ship blockage on supply chains, and the current Covid-19 pandemic further shows disruptions driven by unpredictable events. In the beginning of the outbreak starting in China in early 2020, a massive logjam of containers in Chinese ports waiting for export to the UK and then Europe, further challenging the resilience of supply chain networks.

Incorrect cost estimates or schedules and poor project planning often occur during the ***planning & forecasting*** period of projects (Rudolf & Spinler, 2018). Specifically, these include inaccurate initial time and resources projections (Taylan et al., 2014) related to inventory, procurement, transportation (Aloini et al., 2012) as well as evaluation, testing or installation of products (Western Australian Government, 2021). Other reported risks related to supply chain planning involve inadequate preplanning studies for projects (Hwang et al., 2018). Another planning risk relates to behaviour called *planning fallacy* which occurs when planners made decisions based on delusional optimism that overlook mistakes or miscalculations on weighting of gains and losses, resulting in failures in delivering expected outcomes (Flyvbjerg et al., 2009).

Consequences, including project delays and extra capital or operating costs due to disorganized schedules and resources deployment can be further exacerbated as a result of inadequate ***communication*** in information sharing (Luo et al., 2019), knowledge transfer, change management, partnership performance and integration of materials and information flows (Aloini et al., 2012). In many cases, information is not correctly, efficiently or timely conveyed among project team members due to ineffective communication or conflicts between team members or between different stakeholders. This frequently occurs in joint projects where relationships among project partners are poorly defined or maintained (Pozin & Nawi, 2016), leading to misunderstanding of their roles and responsibilities (Western Australian Government, 2021).

Inadequate IT systems, as part of managing the supply chain operations, can be a critical risk factor, which also affects communication, coordination and the integration of materials and information flows (Aloini et al., 2012; Spekman & Davis, 2004). These all result in inconsistency between the demand and the production, disrupted production and increased costs and delayed delivery and completion of projects (Luo et al., 2019).

Supply chain operation may also suffer from fragmentation and disconnection due to risks associated with ***logistics*** such as limited transportation (Hwang et al., 2018), and inefficient logistic and material delivery processes (Asri et al., 2016). Other disruptions are caused by prolonged customs procedures (Lu and Yuan 2013), import duties and embargos on product importation (Burtonshaw-Gunn, 2009). As a result of the recent reintroduction of customs controls at the border between the UK and EU due to Brexit, imports and exports have experienced significant delays. This, along with Covid-induced growth, has created an increase in demand for additional storage space with the construction of extra warehouses as a precautionary measure. However, such projects are being disrupted due to materials and labour shortages[5].

In supply chain management, companies might experience cash flow issues due to inefficient ***cash flow management.*** This occurred with failures in developing accurate cash flow estimates linked to actual budget and strategic plans and improper cost control measures (Ameyaw & Chan, 2015), impacting a firm's financial capacity. Risks related to ***inventory*** include over-ordering, excessive or mismatched inventory due to mismanaged supply chains (Christopher & Lee, 2004). This might occur more frequently under unexpected turbulences with uncertainty in customer demand and unpredicted events, as what happened under the current Brexit and Covid crisis.

It is important to consider social dimensions in identifying supply chain risks with incorporation of ***corporate social responsibility (CSR)*** that reflect a firm's obligations to societies and the effects on the firm's reputation (Spekman & Davis, 2004). CSR-related procurement risks might be associated with legal, ethical or environmental responsibilities (Carter & Jennings, 2004). While outsourcing to suppliers generates benefits for firms, a lack of control over performance can create CSR issues that, if not identified and managed, far outweigh

[5] https://www.raconteur.net/supply-chain/space-race-why-big-sheds-have-become-hot-property/

cost or strategic advantages gained from the supply chain (Spekman & Davis, 2004). Examples include sourcing products in developing countries that may induce issues ranging from worker rights to child labour/working children that are not socially acceptable labour practices, as happened with Nike being boycotted due to using child labour in developing countries in 1990s (Tang & Tomlin, 2009). A lack of environmental consideration within supplier activities can lead to public objection to the execution of the project (Ameyaw & Chan, 2015).

While ***experience and expertise*** of suppliers are important, those of all professionals involved in the whole supply chain operation also play a crucial part. Different levels of understanding among professionals in relation to demand forecasts, purchasing, transportation, insurance processes and of general supply chain management might create issues. Further, there might be a lack of competencies of practitioners, particularly with inadequate continuing professional development (The UK Institution of Civil Engineers, 2018). Deficiencies in information or experience in procurement for unique or unconventional goods or services might cause inadequately developed specifications or selection criteria (Western Australian Government, 2021).

Supply chain risks might also be related to the risk control process. The first issue is the ***risk management*** process itself. If this is not adequate, then risks may remain unidentified and so unmanaged or problems with the implementation of risk controls may also go unnoticed. ***Quality assurance and quality control (QA/QC)*** is a particularly important form of risk monitoring and review. Possible risks linked to QA/QC include unclear responsibility of practitioners involved from the specification through licensing, purchasing, operation and inspection; inconsistent supervision and oversight to provide assurance in accordance with regulations and national standards, and incorrect or fraudulent documentation on production certification (Commonwealth of Australia, 2018). In many cases, project outputs are not in harmony with design intent, which cannot be easily detected due to poor-quality supervision and assurance. An example of such failures is an overdependence on visual inspection (The UK Institution of Civil Engineers, 2018). Other QA/QC-related risks might be in relation to the lack of checking or audit mechanisms for inspection activities. Fraudulent or misleading certificates of adequacy, especially of imported products, is one of the potential reasons why the use of non-conforming and non-compliant materials has become prevalent. The case of external wall cladding in so many buildings in Australia during the last 30 years is a typical example that presents the risks associated with product substitution that have been overlooked by the QA/QC process (Commonwealth of Australia, 2017).

3.1.2 Supplier

Risk factors within the supply side refers to those that can adversely impact activities and functions undertaken by the suppliers in providing the goods or services as specified by the purchasing organizations. Main stakeholders on the supply side might include manufacturers and suppliers of equipment, materials, products and services, specialist contractors and transporters. In this report, they are referred to as suppliers. Table 5 summarizes risk sources from the supply side that have been reported in the literature.

Table 5. Risks in the supplier category

Risk source	Examples of risk events
Performance & operations	Operational contingencies (e.g., equipment malfunction, machine breakdown)
	Design shortcomings/failures
	Technical/local disruptions in production (strikes, fires)
	Disruptions/delays in distribution of goods/services
	Inadequate inventory and internal information/material flow management
	Deliverables do not meet expectations
	Errors/delays in testing and installation
	Unable to fund or claim for loss or repairs for damage
Financial stability	Suppliers goes out of business, bankruptcy, insolvency
	Cash flow issues
	Increasing inventory costs due to obsolescence, markdowns and stock-outs

Risk source	Examples of risk events
Supplier behaviour	Committed fraud, bribery, modern slavery or money laundering convictions Corruption and collusion in bidding Opportunistic behaviour (e.g., abusing information asymmetry) Non-conforming, and counterfeit, fraudulent and suspect products Fraudulent or misleading certification credentials
Infrastructure & resources	Shortages of human resources Inadequate planning in arranging resources Disruptions in utility supply (power, water, etc.) IT system breakdowns or threats (cyber-attacks, hardware failures) Local human issues (theft, vandalism, sabotage) Industrial accidents
Supplier environment & market	Fluctuations in raw material costs, sourcing market volatility and shifts in customer demand Fluctuations in currencies and prices Geopolitical disruptions, natural disasters, technology failures and pandemics Unpredictability of changes in product technology and market risks
Supplier experience & expertise	Slow to adapt to changes in technology or product design Lack of the ability to conform to specifications
Sub-suppliers	Limits related to source, availability and quality of raw materials Lack of transparency and traceability of Tier 2+ suppliers' materials Lower quality of substituted products

Performance and operations of suppliers are likely to have a significant impact on the provision of goods and services that meet expectations. Risks in this category include operational contingencies due to equipment malfunctions, machine breakdowns and systemic failures (Wagner & Bode, 2009). Performance problems might arise as consequences of uncontrolled changes deviating from the specification or design intent through manufacturing, fabrication and construction that are not reflected in contractual agreements. Technical or local disruptions due to human-centered issues such as strikes or fires might also lead to the downtime of production capacity (Kleindorfer & Saad, 2005).

Other recognized risks related to the performance and operations on the supply side include issues associated with the physical distribution and transport of goods/services due to poor logistics performance of either suppliers or service providers (Wagner & Bode, 2009), and inadequate inventory management of the suppliers. There are also possibilities that goods and services deliverables do not meet expectations, the delivery and testing are delayed, and installation has errors (Li et al., 2017). Loss or damage of goods or services might happen during delivery, as a result of external factors such as extreme weather conditions, vandalism or strikes. There might be risks associated with contractors not being able to adequately fund or claim for loss or repairs for damage or injury (Western Australian Government, 2021).

Financial stability of suppliers plays an important role in good/services delivery as it can affect the production continuity of the supplier. A major financial risk source of supply chains is cash flow issues, including increasing cash flow volatility which might lead to cash shortfalls for firms (Bates et al., 2009). The inability of firms to produce positive operating cash flows or unforeseen negative changes to cash flows might result in firms being unable to meet their cash requirements to maintain their operation (Harris & Roark, 2019). If suppliers encounter cash flow problems, production can be interrupted, affecting the supply continuity of goods and services. Another type of disruption might occur due to an abrupt discontinuity of supply as a main supplier goes out of business, bankruptcy, or other less severe forms of financial distress (Wagner & Johnson, 2004). Excessive or mismatched inventory can lead to significant inventory costs or direct losses due to obsolescence, markdowns and stock-outs (Christopher & Lee, 2004).

The provision of high-quality goods and services throughout the supply chain also significantly depends on ***supplier behaviour***. Risks in relation to supplier activities and behaviour might affect the continuity of the supplier and result in the temporary or permanent perturbation of termination of the buyer-supplier relationship. These include the consequences of committed fraud, bribery, corruption and collusion in bidding, modern slavery or money laundering convictions (The UK Institution of Civil Engineers, 2018; Wagner & Johnson, 2004). Opportunistic behaviour from suppliers, interpreted as “the breaking of explicit or implicit contracts between partners within the supply networks” (Seiter, 2009), can also be a source of supply risks in cooperative settings. A typical example is that suppliers abuse information (e.g., pretending that costs are higher to seek a higher price). The level of this behaviour will increase in the absence of high quality of communication and inter-organizational cost accounting between parties (Seiter, 2009).

Other risks associated with supplier behaviour reside in the use of non-conforming, and counterfeit, fraudulent or suspect products or materials, which is a growing global concern particularly in the construction industry due to high upfront investments (Naderpajouh et al., 2015). This not only impacts the project schedule but also incurs extra costs and creates safety and environmental consequences.

It is also important to recognize risks inherent in supplier ***infrastructure and resources***. Limits in resources such as unavailability or shortages of skilled and unskilled workers have the potential to constraint the production capacity (Khallaf et al., 2018). This impact of poor planning in arranging resources can propagate through the supply chain, such as a slow response to design change, and this is further exacerbated if resources need to be allocated among multiple projects at the same time (Luo et al., 2019). Other infrastructure and resources risks include disruptions in the supply of utilities (e.g., electricity, water), threats to IT systems (e.g., cyber-attacks, hardware failures), local human-related issues such as theft, vandalism, sabotage, and industrial accidents (Fiksel et al., 2015).

Changes in external factors beyond supplier control including fluctuations in raw material costs, volatile sourcing markets and shifts in customer demands (Rudolf & Spinler, 2018) are potential risks in the ***supplier environment and market***. Risks resulted from the external environment also include the unpredictability in demand and unforeseen fluctuations in foreign exchange rates. This might not be easy to pass on to customers in terms of price changes, potentially causing financial stability problems for the organizations (Wagner & Bode, 2009) or conflicts between suppliers and buyers. Other external conditions impacting manufacturing capacity and delivery capability of suppliers involve geopolitical disruptions, natural disasters, technology failures, pandemics (Fiksel et al., 2015), the unpredictability of changes in product technology, and market risks such as behaviour of competitors.

Supplier experience and expertise are also important in ensuring effective supply of goods and services. Suppliers might be slow in adapting to changes in technology or product design that may have disadvantageous consequences on costs and competitiveness of products in the market and lead times (Zsidisin & Ellram, 2003). With the globally increased reliance on outsourcing, these risks might be amplified (Giunipero & Aly Eltantawy, 2004) while purchasing firms have to rely on improvement efforts from suppliers to remain efficient in their production process (Zsidisin & Ellram, 2003).

Finally, main suppliers might heavily rely on ***sub-suppliers,*** which leads to exposure to risks related to the source, availability and quality of raw materials, and the transparency and traceability of Tier 2+ suppliers’ provision. In regard to product substitution, for example, sub-contractors might use inferior and cheaper products or materials that are more expensive when rationally assessed over their full life cycle, compromising the health and safety of both workers and users. This issue has been identified as one of the most significant contributing factors to the prevalence of non-compliant external cladding materials on Australian buildings (Commonwealth of Australia, 2018). All the identified supplier risks also apply to each sub-supplier thereby increasing overall risk exposure.

3.1.3 External environment

Risks in the environment category (Table 6) are changes in external factors beyond a firm's control that can adversely impact the supply chain. These include legal, political, social and economic risks in human systems and threats and hazards in natural systems happening outside the internal supply chain environment. Regulatory, legal and bureaucratic risks refer to the unexpected degree and frequency of changes in ***laws and regulations*** and the impact of legal enforceability and execution on the supply chain (Wagner & Bode, 2009). An example of potential risks is the difficulty to obtain approval required for supply chain design and operations, as the procedures might be excessive (Taylan et al., 2014) and out of the individual supply chain or firm's control. Specifically, supply chain operations can be disrupted by administrative barriers such as customs or trade regulations. Newly introduced regulations are often abrupt and difficult to anticipate, which substantially affect the costs and the redesign of systems to conform legal requisites (Wagner & Bode, 2009). Legal changes also likely result in changes in the validity of the project contract after the promulgation of the contract (Song et al., 2013). In some other cases, inadequate legislation might be easily eluded, such as in the case of building regulations in Australia. The weakness in the certification process and the lack of proper regulatory controls on the use of building products have provided pathways to evade Australian Standards in the National Construction Codes (Commonwealth of Australia, 2018). There have been significant delays in designing and implementing relevant policies to address the prevalent non-compliance and non-conformity in the building sector (Commonwealth of Australia, 2017).

Table 6. Risks from the external environment

Risk source	Examples of risk events
Laws & regulations	Unexpected changes in laws and regulations Excessive approval procedures Administrative barriers including customs and trade regulations Inadequate legislation
Standards & codes	Standards & codes are not strictly followed Unclear standards or codes, causing evasion
Economic	Inflation, tariff, fiscal policies Financial risks include financing structure, credit and other government financial policies
Political & governmental	War, civil disorder Deliberate threats including sabotage, terrorist attacks Labour disputes Social-political instability
Natural events	Natural disasters (earthquake, tsunami, hurricane, flood, etc.) Adverse weather conditions (e.g., lightning, strong wind, etc.)
Environmental, health & safety	Pandemic, epidemic Hazardous materials or activities on the site Traffic accidents Violation of environmental regulations
Sociocultural	Criminal acts (theft, robbery, assault, etc.) Civil torts, substance abuse

New policies or revised ***standards and codes*** sometimes drive changes in contractual terms and conditions, which suppliers may not strictly follow as this will incur high costs. Other reported risks include unclear standards or lack of clarity in the national codes with too broad provisions might create a room for evasion, as in the case of non-compliance in the building industry. Specifically, it is difficult to establish if construction materials and products imported to Australia comply with the existing national standards. Furthermore, some stipulated information is vague which likely leads to risks associated with integrity, credibility and effectiveness of certification credentials of imported materials. Since the codes governing the built environment in Australia are performance-based, there is no obligation to adopt any particular material, design factor or construction method. While this performance-based code design has provided advantages, including innovative building and cost-effective projects, a lack of clarity in the national codes has created some conditions for the prevalence of non-compliant elements (flammable cladding materials) in the building industry (Commonwealth of Australia, 2017).

Other risk in this category come from ***economic*** fluctuations including inflation, tariff and fiscal policies, financial risks including financing structure, credit or government policies (Ameyaw & Chan, 2015). ***Political and governmental*** disruptions triggered by war, civil disorder, and deliberate threats including sabotage, terrorism and disputes with labour or other groups (Fiksel et al., 2015) might also significantly affect the supply chains. Their operation is susceptible to socio-political instability and economic disruptions (Kleindorfer & Saad, 2005), which are amplified particularly due to the increase in global outsourcing. These threats can impact supply chains both directly and indirectly. For example, Ford and Toyota experienced massive disruptions in the materials flow into their plants in North America right after the 9/11 terrorist attack due to the US border shutdown (Wagner & Bode, 2009). Recent interruptions in supply chains were also reported with massive queues at English ports in late 2020 after Brexit[6].

Another category of vulnerability is catastrophic risks derived from ***natural events*** including earthquakes, volcanic eruptions, tsunamis, droughts, hurricanes, storms, floods and wildfires, which cause disruptions and losses in production facilities and transportation. According to the U.S. Federal Reserve, more than 40% of Minnesota manufacturers were negatively impacted by the 2011 tsunami in Japan (Fiksel et al., 2015). Not only natural disasters but also the seasonal fluctuation of weather such as variations in wind speeds, wind gusting, temperatures, lightning strikes, etc. might contribute to risks in project operations (Edwards et al., 2020).

Vulnerabilities from other external pressures might originate from the unexpected ***environmental, health and safety*** factors, including pandemics or epidemics, hazardous materials present or activities undertaken on the site (Western Australian Government, 2021), and traffic accidents (Luo et al., 2019). Environmental risks might arise from violation of environmental regulations that incur additional costs to continue project activities (Xu et al., 2015).

Global supply chains have suffered from massive disruptions in recent months due to the Covid-19 crisis with increased demand coupled with lockdown-induced production outages and capacity shortages. While supply deficit has already been widespread, panic ordering and stockpiling – a classic bullwhip effect in customer behaviour have further exacerbated the situation[7]. Challenges of the pandemic might remain for a long time, depending on the resilience of supply chains to be able to return to the pre-pandemic operation levels.

Finally, ***social and cultural*** issues, such as criminal acts (e.g., theft, robbery, assault, etc.), civil torts, and substance abuse, are other influences that do not specifically target an individual firm but can indirectly create business constraints or barriers (Burtonshaw-Gunn, 2009; Edwards et al., 2020).

3.1.4 Cooperation and trust

Behavioural risks have often been overlooked although they occur frequently and can adversely impact the supply chain operations. These risks result from individual and organizational factors including mistakes, attitudes, corporate cultures and behaviours (Table 7), which can interrupt the supply networks and cause not only short-term losses but long-term underperformance (Seiter, 2009). Although engineered structures are vulnerable to uncertainty inherent in natural disasters, these events are statistically rare. “Uncertainty in engineering mostly arises from unpredictable human behaviour” (Trevelyan, 2014).

Note that issues linked to experience and expertise have been covered in other categories as have extreme supplier behaviours linked to illegal or unethical behaviour. Risk sources addressed in this section relate to ways

[6] https://www.raconteur.net/supply-chain/black-swan-attack-can-world-trade-take-any-more-trauma/
[7] https://skilldynamics.com/digital-learning-powers-supply-chain-resilience/

of working together within the supply chain. The primary issue is trust where a lack of trust increases the likelihood of many of the supply chain and coordination risks listed above.

Table 7. Risks linked to cooperation and trust

Risk source	Examples of risk events
Trust issues	Opportunistic behaviour No mindset of "Pain/Gain sharing" Lack of mutual commitment, organization, coordination, collaboration and teaming
Culture issues	Misfit of corporate cultures Poor organizational culture (inadequate knowledge transfer or information sharing) Lack of deference to expertise
Conflict	Lack of effective dispute resolution Confusion over responsibilities

As the number of partners increases in a global supply chain, the level of visibility and control of operations can be reduced significantly, potentially inducing harmful and destructive behaviour (Rudolf & Spinler, 2018). Due to a large number of suppliers and contracts in large-scale projects, ***trust***-related behaviours such as *opportunism* can arise (Christopher & Lee, 2004; Rudolf & Spinler, 2018). Opportunistic behaviour occurs as a result of asymmetric information between partners within the supply networks which creates opportunities for breaking either explicit or implicit (or formal/informal) agreements (Seiter, 2009). Other examples of significant trust-related risks are no mindset of "Pain/Gain sharing" (Rudolf & Spinler, 2018) and the lack of mutual commitment, collaboration and teaming (Khallaf et al., 2018).

Culture issues are another source of risks. *Misfit of corporate cultures, poor organisational culture*, including failures to transfer knowledge, to follow up on concerns or to share lessons learned from past incidents and near misses, and a *lack of deference to expertise* can be common. Incidents might occur in supply chains whereby managerial views are always prioritized than operation-level expertise. This might lead to internal ***conflicts*** and consequently improper management of projects (Ameyaw & Chan, 2015).

For large infrastructure projects, delivery strategies often include joint ventures (JVs) i.e., collaborative contracting between project partners with differing but complementary skills to deliver a larger project than either organisation could do individually. There are some specific risks related to cooperation and trust that apply in this situation. Empirical work by Lu et al. (2020) across projects on several continents showed four key factors as obstacles to JV success, or in other words increased risk. The factors are:

- Unfair and ineffective management
- Lack of communication, understanding and mutual trust
- Policy, management style and
- Organizational cultural differences

Given the importance of effective management of trust and avoidance of conflict, brief literature reviews are included below on these two subjects.

3.1.4.1 Trust

One key behavioural issue in managing procurement risk is trust between organisations along the supply chain (Cerić et al., 2021).

Trust can be defined as "a decision to become vulnerable to or dependent on another in return for the possibility of a shared positive outcome" (Cerić et al., 2021). The project management literature discusses trust as interpersonal, inter-organisational and intra-organisational. Arguably, the latter two rely on interpersonal trust although this is often represented in practice by trust in systems rather than relying completely on interpersonal relationships.

Trust enhances cooperation, reduced the incentive to 'check up' on other parties and is a substitute for control (Cerić et al., 2021; Lau & Rowlinson, 2011). Considerations of maximising the value of trust has led to increased use of partnering-type contracting strategies. In this way, trust has become an important governance mechanism playing a mediating role between supply chain members. Low trust increased uncertainty and so risk to project outcomes.

Wong et al. (2008) have conceptualised trust as having three components:

- Cognition-based trust built on knowledge and communication;
- System based trust founded on faith in the system; and
- Affect-based trust based on a sense of belonging.

Their empirical validation of the model suggests that all three components are important. With this in mind, we see trust as a moderating factor for all risks that are internal to the supply chain rather than a source of risk in its own right. Weakened trust makes a system more vulnerable to potential problems that arise and conversely strengthened trust makes the system more resilient. The literature regarding trust in supply chain management therefore gives insights into potential procurement risks that may arise.

There are many models in the literature of factors to develop trust. One of the most practical is a model for developing trust on US construction projects developed by Issa et al. (2018). The model operates from the contractor's perspective and suggests that in any given situation, project activities that require higher levels of trust (such as constructability reviews and value engineering studies) are identified along with context factors (such as stakeholder backgrounds and expectations). Overall, based on literature review and empirical work in the US construction sector they identified the following trust weakening and trust strengthening factors from the contractor's perspective. Their model is risk based and so suggests that these factors increase or decrease project risk via the mechanism of trust (Table 8).

Table 8. Factors weakening and strengthening trust

Trust weakening factors	Trust strengthening factors
Excessive use of electronic communications	Face to face communications
Not respecting informal agreements	Working with signed contracts and complete drawings and specifications
	Consistently honouring informal and formal agreements
Use of separate project management company	Working with owners
Excessive change orders	
Using a third party to review corrective change orders	
Unclear benefits of using new technologies and/or work processes	
	Working to realistic project schedules
	Pay fairly and on time
	Timely and adequate response to RFIs.

Referring back to Wong et al. (2008)'s components of trust, this model addresses factors of all three types although the affect based component is perhaps indirect.

The study by Manu et al. (2015) based on four UK case study projects reaches somewhat similar conclusions with key factors influencing trustfulness and trustworthiness identified as being:

- Job performance (which drives consistency of outputs and overall ability to meet the program)
- Perception of future work opportunity (which encourages a longer term view on all issues and so greater short term flexibility)
- Economic climate (which determines the extent of emphasis on cheapest price and so minimum profit margins giving less flexibility)
- Change management process (which needs to be seen as fair on both sides)
- Payment practices (paying what is due for work completed in a timely manner)
- Project specific circumstances (local, idiosyncratic issues can also play a role)

Again, this model covers system-based, cognition-based and affect-based components at least to some extent although it also considers the impact of environmental factors such as economic climate which is not explicitly included elsewhere.

3.1.4.2 Conflict

There is also a literature linked to sources of conflict in construction. In this review, we conceptualise conflict not as a source of risk in its own right, but rather a sign that risks are manifesting. In this way, data drawn from the literature on sources of conflict provides a cross check on risks. Jaffar et al. (2011) have reviewed the literature on conflict in the construction industry and created a taxonomy that we have augmented based on the 2021 Global Construction Disputes Report (Arcadis, 2021) (Table 9).

Table 9. Taxonomy of sources of conflict in construction

Contractual problems	• Lack of flexibility • Errors or omissions in technical specs that form part of the contract • Unrealistic expectations (time and/or cost) • Risk and rewards not shared evenly • Problems with schedule management
Technical problems	• Lack of information to do the job • Slow response to RFIs • Lack of expertise/experience to do the job
Behavioural problems	• Individual personality conflicts amongst key people • Ignorance of contract terms and conditions • Potential for loss of face / ego issues • Lack of alignment of needs • Lack of team spirit / lack of trust

3.1.5 Consequences from procurement failures

The right-hand side of the Bow Tie model indicated that if controls are not in place, or the procurement process is not well managed, the consequences on assets or environment and harm to people are inevitable. Table 10 summarized potential socioeconomic, environmental and legal consequences resulting from failures in procurement risk management. The following section provided analysis of past incidents when procurement failures occurred which resulted in unplanned adverse outcomes.

Table 10. Consequences from failures in procurement risk management

Consequence category	Example of consequence
Economic	Extra capital costs Extra operating costs Project delay Contract breach External costs Poor interface with existing operations
Environmental	Pollution (air, land, water) Reduced sustainability Land degradation Impact on flora/fauna/wildlife habitats Noise Odour
Social	Worker safety Public safety Modern slavery Workplace/public health Culture/heritage damage
Legal	Criminal charges Licences revoked
Reputational	Reputational loss or damage

3.2 Procurement failures in past incidents and lessons learned

The next step of the literature review is to investigate procurement-related incidents and their associated adverse consequences, and draw lessons learned from those failures. We look at 19 incidents in different sectors, including construction, transport, energy, aviation, and oil and chemical process industries to explore why procurement went wrong and what can be learned from them to prevent the recurrence of future procurement failures (Table 11). Main issues associated with procurement range from the use of non-compliant or non-conforming materials or products to specification or design failure and inadequate planning or selection of contractors.

Table 11. List of procurement-related incidents

	Incident	Sector
1	Lacrosse apartment fire (2014)	Building
2	Grenfell tower fire (2017)	Building
3	Hyatt Regency walkway collapse (1981)	Building
4	Opal Tower cracking (2018)	Building
5	Channel Tunnel (1985-1994)	Infrastructure
6	Demolition of the Royal Canberra Hospital (1997)	Infrastructure
7	I-90 Tunnel ceiling collapse (2007)	Infrastructure
8	Berlin-Brandenburg Airport project delay (2011-2020)	Infrastructure
9	NSW public transport failures	Infrastructure
10	The CBD and South East Light Rail project (2011-2020)	Infrastructure
11	Loss of Space Shuttle Challenger (1986)	Aerospace
12	Boeing 737 MAX failure (2018)	Aviation
13	The Myki ticketing system failure (2005-2014)	ICT-based transport
14	HMAS Westralia ship fire (1998)	Maritime
15	South Korean nuclear reactor shutdown (2013)	Energy generation
16	Cabin Creek Hydroelectric Tunnel Fire (2007)	Energy generation
17	Explosion at Shell in Moerdijk (2014)	Chemical process industry
18	Donaldson Enterprises, Inc. Fatal Fireworks Disassembly Explosion and Fire (2011)	Chemical process industry
19	Buncefield explosion and fire (2005)	Oil industry

3.2.1 Lacrosse apartment fire (2014)

On the early morning of 25 November 2014, the 23-story Lacrosse apartment building in La Trobe Street, Docklands, in Melbourne suffered a serious cladding fire, which resulted in the evacuation of about 450-500 people. The fire was ignited by a cigarette on a balcony and spread to the building cladding. The damage caused to the building was significant and the claimed losses exceeded $12 million. Fortunately, no loss of life was caused by the fire.

In their Post Incident Analysis Report, the Metropolitan Fire Brigade (MFB) identified that the rapid spread of the fire was caused by the non-compliant use of aluminium composite panels (ACP) on the building's external walls (Metropolitan Fire Brigade, 2015). APCs are increasingly used by designers and builders worldwide as feature panels or lining to provide a decorative finish to the external walls of buildings. ACP is a multi-layered building product comprising a core material in between aluminium sheets which are glued to form a laminated product (Victorian Building Authority, 2016). The brand of the ACP product used on the Lacrosse building was Alucobest, which had a combustible polyethylene core material.

The Lacrosse building fire caused by ACP cladding is not a standalone case in Melbourne. On the morning of 4 February 2019, the 41-storey apartment complex called Neo200 at the Spencer Street caught fire. The spread of fire was also caused by combustible ACP cladding. The Neo200 building had similar procurement issues to the Lacrosse building, which led to the installation of combustible cladding on the building.

Non-compliant use of ACP cladding

Given the use and number of stories, the Lacrosse apartment building is considered as a Type A construction under the Specification of the Building Code of Australia (BCA). BCA outlines the requirements in the design and construction of new buildings. The building solutions allowed for in the BCA are "Deemed to Satisfy" solution or an "Alternative Solution" (Genco, 2015). According to the deemed-to-satisfy requirements of the BCA, external walls of Type A buildings must be non-combustible. Specifically, BCA defined "non-combustible" as: "*Applied to a material – not deemed combustible as determined by AS1530.1 -Combustibility Test for Materials; Applied to construction or part of a building - constructed wholly of materials that are not deemed combustible*" (Metropolitan Fire Brigade, 2015, p. 27). Investigation into the Lacrosse building fire revealed that the Alucobest APC neither meets the criteria nor has been effectively tested in accordance with AS1530.1. (Metropolitan Fire Brigade, 2015). Therefore, the use of Alucobest ACP as external wall cladding specified in the building permit application should be considered as an Alternative Solution. For a material or building system to be used as an Alternative Solution, BCA requires that evidence of suitability for the material and form of construction should be provided, for example, in the form of a Certificate of Conformity or a Certificate of Accreditation. However, during the investigation process, MFB was not able to gain such documents for the Alucobest ACP product and reported that Alucobest products were even not included in the Australian Building Codes Board – Register of CodeMark Certified Products (Metropolitan Fire Brigade, 2015). This suggests procurement issues in relation to quality assurance/control and inadequate regulation enforcement.

Knowledge and responsibilities of building professionals

The selection of ACPs as the cladding for the Lacrosse building was also associated with the problem of experience and expertise of building professionals. When the ACPs were installed on the Lacrosse building in 2011, there was a generally poor understanding among building professionals in terms of the fire risks associated with ACPs, and the Victorian Civil and Administrative Tribunal's hearing regarding the Lacrosse building fire case indicated that there is no reason to expect the builder to have a better understanding than that of architects, building surveyors or fire engineers.

A building surveyor is responsible for lodging with Council a copy of the building permit and all associated documentations to approve that the building can be built complying with the Act, Regulations and BCA. However, insufficient documentation was found in the case of the Lacrosse building. A review of the documentation lodged by the private building surveyor with Council by MFB highlighted that: the documentation did not provide sufficient details to determine whether the façade wall was designed to be non-combustible or not; no evidence was shown in the fire engineering design report as to whether the wall was considered to be not non-combustible; and no document proving that the cladding system was approved or accredited (Metropolitan Fire Brigade, 2015).

It is not uncommon that product substitution occurs on building sites. The due process under contractual requirements is that a contractor or a sub-contractor makes application to the supervising architect or project manager for changing a specified material. A request for variation is normally sought, and a revision to the building permit is required if the variation is an essential safety measure or method of construction. The original cladding specified by the architect to be used on Lacrosse building was named “Alucobond”, which is an accredited product and has a CodeMark Certificate of Conformity from the Australian Building Codes Board. The products of Alucobond and Alucobest are similar in appearance and are not able to be differentiated by simple visual inspection. However, Alucobest is not certified and does not have technical specifications available for supply in Australia. In changing the cladding product, a revision to the building permit would have been required. However, no evidence in the documents lodged by the building with Council shows that a request for revision of the building permit was considered (Metropolitan Fire Brigade, 2015).

The hearing of the Lacrosse building fire case revealed that the incident is the result of multiple building professionals failing to perform their responsibilities and exercise care. Specifically, in installing the cladding:

- the contractor breached the warranties implied in the Design and Build contract under the Act in respects of: 1) suitability of materials; 2) compliance with the law (which includes the BCA); and 3) fitness for purpose (Victorian Civil and Administrative Tribunal, 2019, p. 7).
- the building surveyor failed to exercise due care and skill in: 1) issuing the building permit that approved the architect’s specification of ACPs “indicative to Alucobond”, which did not comply with the BCA; and 2) “failing to notice and query the incomplete description of the cladding systems” in the fire engineering report (Victorian Civil and Administrative Tribunal, 2019, p. 7).
- the architect failed to exercise due care and skill in: 1) failing to remedy defects in building design which rendered it not fit for purpose; and 2) failing as head design consultant, to ensure the ACP sample provided by the builder was compliant with the architect’s design intent. It was revealed that the architect was liable for approving the builder’s substitution of Alucobest, which the architect approved based on warranty and colour and requested confirmation of specification requirements being met.
- the fire engineer failed to exercise due care and skill in: 1) failing to conduct a full engineering assessment of the Lacrosse tower; and 2) failing to recognise the ACPs proposed for use in the Lacrosse tower did not comply with the BCA and failed to warn at least the contractor (and probably also the building surveyor, the architect and the superintendent) of that fact (Victorian Civil and Administrative Tribunal, 2019, p. 8).

Procurement lessons to be learned

1. Inadequate enforcement of regulation has allowed the non-compliant building products to be used on the Lacrosse building. Specifically, the surveyor issued the building permit that approved the use of an unfamiliar building product without asking for evidence of suitability, breaching the requirements of Building Code of Australia. Certain forms of monitoring or auditing of regulation officers’ performance should be in place to ensure that enforcement standards are maintained.
2. Building professionals’ lack of experience or expertise with new products or materials: Building practitioners demonstrated a poor understanding of the new building product and associated risks. In the case of Lacrosse building, it appears that building professionals also had a poor knowledge of what products were accredited and what products were not accredited. This highlights the importance of information sharing at the industry level, for example through an electronic repository with updated information of new materials or products. Making this information accessible and available to professionals helps them to make informed decision about product specifications.
3. Lack of professional responsibility and accountability was a clear issue in the Lacrosse building case. There is the need to develop relevant Code setting out the standards of professional conduct and provide continuing professional development to enhance professionals’ sense of responsibility and accountability.

4. Insufficient documentation and incomplete design information submitted for building permit application were identified in the case of Lacrosse building. It is necessary that detailed full plans with complete design information and clear specifications are reviewed and approved by relevant decision-makers, ensuring that the plans meet all relevant standards.
5. An effective change management process is missing the Lacrosse building case. Any substitution of product or material needs to be reported, reviewed and approved by relevant persons. This ensures that the new product still meets the requirements of specifications and achieves the intended performance.

3.2.2 Grenfell tower fire (2017)

The 24-storey Grenfell Tower was part of the Lancaster West Estate, which is a council housing complex in North Kensington, West London. Grenfell Tower together with other council housing were originally managed directly by the Royal Borough of Kensington and Chelsea Council (RBKC) until 1996 when the council established the Kensington and Chelsea tenant management organisation (KCTMO) under the UK Government's Housing (Right to Manage) Regulations 1994 to manage the council housing stock (MacLeod, 2018).

A major refurbishment was conducted on the Grenfell Tower during 2014-2016. The refurbishment involved installing an insulated rainscreen cladding system covering the exterior of the building. The cladding system consists of combustible polyisocyanurate (PIR) foam insulation and aluminium-polyethylene composite material, separated by a ventilated cavity (McKenna et al., 2019). The cladding system is depicted in Figure 3.

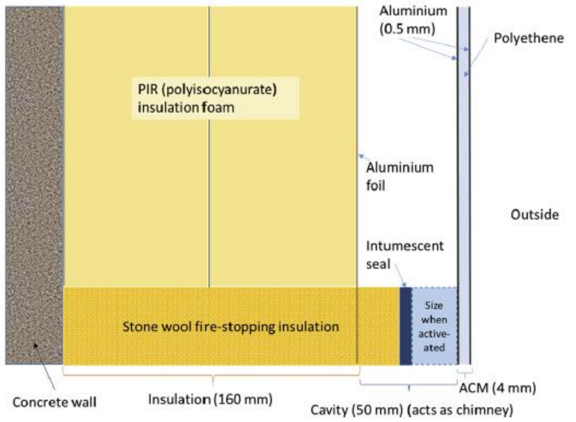

Figure 3. The cladding system used in Grenfell Tower (McKenna et al., 2019, p. 116)

Early on the morning of 14 June 2017, a fire broke out in a fourth-floor flat in the Grenfell Tower. The fire, caused by a malfunctioning refrigerator, spread rapidly to the building's external cladding. Crews from the London Fire Brigade arrived within six minutes and later were joined by firefighters and fire engineers from stations across London as well as the London Metropolitan Police Service (MacLeod, 2018). By the time the blaze was extinguished, 72 residents had lost their lives and additional 71 had been injured. It was the deadliest structural fire in the UK since the 1988 Piper Alpha disaster and the worst UK residential fire since the Second World War. Investigations into the Grenfell Tower fire revealed that the combustible material used in the building cladding was the cause for the rapid spread of fire (McKenna et al., 2019). The cavity between the cladding and the insulation acted like a chimney to spread the fire. This incident clearly indicates a failure in procuring safe and compliant building materials.

Replace the cladding with a cheaper version

The Inquiry into the Grenfell Tower fire identified cost-driven behaviours of the client organisation, suggesting a poor organisational culture. Documents released by the RBKC Housing and Property Scrutiny Committee from 2013 revealed that the company Leadbitter, who was the original contractor scheduled to carry out the Grenfell refurbishment work, was dropped by KCTMO-RBKC because its quotation of £11.278 million was £1.6 million above the budget proposed by KCTMO-RBKC (MacLeod, 2018). The contract was put back out to competitive tender, and the other company Rydon was then appointed as the contractor to carry out the work with a quotation of £8.7 million (Hills, 2007). The scopes of work set out for both companies were similar, with the latter company agreeing to carry out the work for £2.5 million less. This suggests contractor evaluation and selection were a problem. It appeared that KCTMO-RBKC selected the contractor primarily based on the criterion of cost, overlooking the factors of quality, the standard of work and competency.

A project execution strategy of Design and Build (D&B) was used in the Grenfell Tower refurbishment project. Under the D&B strategy, consultants (e.g., architects and engineers) undertake the concept design stage of a project, which will then be passed on to the D&B contractor (in this case Rydon) to complete the detailed design and construction stages. Leadbitter's original plans included recommendations from architects and engineers, who undertook the concept design, to adopt a zinc composite external cladding with a fire-retardant core. The fire-resistant zinc cladding was also approved by residents of Grenfell Tower. However, RBKC implemented a value engineering initiative with the aim of saving costs. Evidence showed that amendments were made to the contract between KCTMO and Rydon after tender to save £293,369 by replacing the cladding with cheaper aluminium panels, which contain a polyethylene core that was proven to be more combustible in tests and banned on building higher than 12 meters in Germany and the US at that time (MacLeod, 2018). Meeting minutes, price outlines and other project correspondence suggested a strong focus on cost-cutting from RBKC with little concern for safety (Construction Manager, 2017).

Testing, certification and inspection of the cladding

The Inquiry into the Grenfell Tower fire revealed compelling evidence that the cladding system failed to comply with the Building Regulations in that it failed to adequately resist the spread of fire with regard to the height, use and position of the building (Moore-Bick, 2019). Cladding using a composite aluminium panel with a polyethylene core should not be used on buildings over 18m in height according to the Building Regulations. This has led to the question of how the non-compliant cladding was approved to be used on the Grenfell Tower by relevant inspection and regulatory bodies. Investigation into the circumstances surrounding the Grenfell Tower fire indicates severe procurement problems in terms of supplier behaviour and quality assurance and control.

The Grenfell Tower Inquiry shows that the suppliers that manufactured Grenfell Tower's cladding "abused" the testing system, deliberately provided misleading information about the performance of their products and circumvented regulations with marketing strategies (Booth, 2020). Specifically, the company which manufactured the cladding sheets, Arconic, obtained a certificate for its polyethylene-filled panels on "a false premise" by providing test reports for a more fire-retardant version of the product. The company Celotex, which manufactured the combustible PIR insulation foam, demonstrated a "widespread culture … of ignoring compliance", including distorting a full-scale fire test of its products. In addition, the company Kingspan, which produced the rest of the insulation, carried out tests that involved "concealing components in a manner designed to facilitate a pass and/or using materials that were not as described in the test reports", including adding fire retardants to materials in order to slow down ignition (Booth, 2020). The unethical supplier behaviour was enabled by the deregulation and privatisation of testing and certification bodies (Voutsadakis & Gonzalez, 2018). The testing and certification are often commissioned by the manufacturers of the products (i.e., self-certified), which is highly problematic because of conflict of interest and lack of independence.

The inability to identify the problematic cladding also suggests the issues of experience and expertise of building surveyors and inspectors and the ineffective enforcement of laws and regulations. Before construction work can commence, full plans or detailed design drawings need to be reviewed and approved by building surveyors to ensure that the plans fully comply with the requirements of Building Regulations. In the Grenfell Tower case, despite the fact that the composite aluminium panels did not comply with the Building Regulations in terms of fire resistance and were not allowed to be used on tall buildings, they were still approved by building surveyors from the local council. This clearly demonstrates surveyors' negligence and ineffective enforcement of regulations. Further, during 2014-2016, sixteen inspections were undertaken by building inspectors on the Grenfell Tower refurbishment project, but all these inspections failed to identify that the building was being clad with material effectively banned on tall buildings by the Building Regulations (Booth, 2017). This raises the concern that whether the building regulation officers were sufficiently competent, which was pointed out by (Hackitt, 2017, p. 55) that there are "no legislative requirements that set standards of competence or training for building control inspectors".

Procurement lessons to be learned

1. The contractor Rydon was selected by the client organisation purely based on the criterion of price. There is a need to change the cost-driven culture. The consideration of cost should be balanced with quality and safety requirements and the contractor's technical competency when evaluating tenders.
2. The supplier demonstrated unethical behaviours of manipulating testings and providing misleading information of the performance of building products. It is important that the purchaser has internal testing and auditing mechanisms in place to verify the information provided by the supplier. In addition, the industry and regulatory bodies should set and apply a clear code of conduct for suppliers, who are held to account for breaching the code of conduct.
3. The privatized material/product testing and certification lack independence and transparency. The privatization of testing and certification can be conductive to unethical behaviours by suppliers. It is important to have the testing and certifying process undertaken by an independent third-party to avoid conflict of interest and provide reliable product or material information.
4. The surveyor in the Grenfell Tower case approved the use of cladding panels that are clearly not compliant with building regulations, suggesting the enforcement is inadequate and ineffective. Auditing mechanisms should be in place to review and monitor the performance of regulation officers and enhance their professional accountability.
5. The ineffective enforcement was partially attributed to the building surveyor's lack of competency. It is important that regulation officers are equipped with adequate skills and clear about their roles and responsibilities, for example through professional development and assessment.

3.2.3 Hyatt Regency walkway collapse (1981)

The walkway collapse at the Hyatt Regency hotel in Kansas City resulted in 114 fatalities and more than 200 people being injured was one of the most well-known failures in structural engineering in recent history. The elevated walkways were designed by an architecture firm owned by Jack Gillum, a structural engineer. Somehow a critical change in the design of the walkways that led to the tragic failure made its way through the design, inspection and construction process without any control.

Cause of failure

On 17 July 1981, a tea dance was held with about 1,500 to 2,000 area residents in the hotel lobby, an innovative space with three walkways extended from the lobby ceiling. Slightly after 7pm, the upper suspension rods suddenly pulled through their connections. This caused the fourth-floor walkway to lose from its support and drop to the crowded lobby floor, crushing the second-floor walkway beneath it. There were hundreds of guests trapped under more than 60 tons of debris (Moncarz & Taylor, 2000).

Investigation of the collapse confirmed that the two channels transferring the walkway loading into the steel rods had deformed, enabling the nuts and washers of the rods to pull through the connection. The as-built connection that consists of two steel rods with the upper rod connecting the fourth-floor walkway to the ceiling and the lower rod supporting the second-floor walkway beneath was “grossly inadequate” (Brady, 2015). This connection was not built as per the original design where there should have been only one rod with a nut and washer transferring the walkway loading into the steel rod. This ill-considered change doubled the load on the fourth-floor walkway connection, resulting in the collapse (Figure 4).

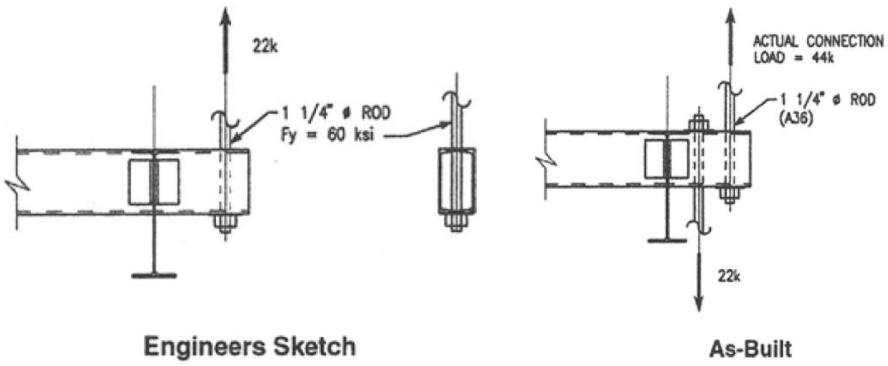

Figure 4. The original detail and as-built connection (Moncarz and Taylor (2000))

The original connection was sketched by Gillum’s firm. The detail was left unspecified by the engineers, indicating that the fabricators were to undertake the calculations for the design. When the fabricator suggested using two rods for the connection, as he thought the original design was impractical, the engineer accepted the suggestion after some quick calculations. Both failed to follow up with a formal application for approval. After the fabricator left for another project, a subcontractor took over the remaining work and used the drawings including the partially completed as-built connection of the walkways from the fabricator, assuming that it had been formally designed. The drawings were finalised, and the issue was not picked up by the designer. The detail was fabricated and installed. Soon after installation, the channels of connections began to deform. The issue was disregarded during and after the inspection by practitioners involved who had noticed it.

This structural failure was clearly induced by organisational issues which led to a critical change in the original design being installed without formal approval and checking by an experienced engineer. Deformations of the connections were noticed and reported by the owner’s inspector, but this was never followed up. Warning signs could have been raised but were somehow disregarded by professionals involved. Although no criminal charges were filed, the engineering firm’s individuals were convicted of gross negligence, misconduct and unprofessional conduct in the practice of engineering (Pfatteicher, 2000). The catastrophic failure left immense aftermath, including legal battles around the loss and the trauma that the rescuers suffered during the rescue effort.

Procurement lessons to be learned

1. The engineer accepted changes to structural elements deviating from the original design, informally allowing the fabricator to proceed with the as-built detail. This is not only an issue of suppliers (e.g., fabricator, contractor, etc.) who did not conform exactly to the original specifications but also the process where formal approval procedures were missing. Any agreed modifications to the original design/specification must be reviewed and formally approved.
2. The subcontractor used the as-built drawings from the fabricator as if it was the design. The whole quality assurance and quality control process was missing, leading to the design flaw that "any first-year engineering student could figure it out" if only it had been checked[8]. Checking of the original detail and final design by a professional with relevant experience and competence is crucial to make sure all modifications and changes are acceptable. Design verification is not only to evaluate compliance but also to identify any perceived deficiencies.
3. Although the faulty connection had been a subject of concern before the accident, indicated through the report of the owner's inspector and the workman's notice of the deformation, the issue was never followed up. Risks might exist in the risk control process itself where inspection work is not under supervision or control. Not only engineers but also managers should have been accountable for following up with warning signs at any stage of the project. All professionals involved in projects should be encouraged to speak up so that their concerns can be seriously heard and followed up.
4. While the Hyatt walkway was a fast-track project with several changes in personnel during the design of specific elements, it failed in transferring the responsibilities from one team to the other. It can be argued that at the time the hotel was design and built, there was no clear definition of responsibilities associated with the design process control. It is crucial to emphasize that responsibilities of all professional involved must always be explicitly defined at the early stage. This, along with effective and clear communication, needs to be maintained throughout the entire project to ensure public safety and quality of built facilities.
5. It is very clear that all professional involved in the Hyatt walkway project lacked common goals and mutual commitment toward the safety of the asset and of the public. Public safety should always be placed at the top of priorities of practitioners. Collaboration and teaming towards safety should not only be reflected in the codes of ethics and professional conduct but also embedded in continuing professional development of workers and at all stages throughout any project. Not only the knowledge and skills of practitioners are required but also the behaviour and commitment towards project success are crucial to operate in complex environment.

[8] Jack Gillum said in one of his interviews: https://web.archive.org/web/20160108175310/http://skywalk.kansascity.com/articles/20-years-later-many-are-continuing-learn-skywalk-collapse/

3.2.4 Opal tower cracking (2018)

Opal Tower is a high-rise residential building located in the Olympic Park suburb of Sydney. The tower has a triangular cross section with 36 stories above ground level and 3 stories below ground level consisting of a total of 392 apartments. The construction of the tower was completed in August 2018 and occupancy commenced in the second half of 2018. On December 24th 2018, residents of the Opal Tower reported loud banging noises of internal origin, which were later found to be associated with cracks in the concrete structural elements. In response, about 3,000 people were evacuated with the help of the police on the same day (Sas, 2018).

Early in 2019, an investigation of the causes of the structural damage to Opal Tower was requested by NSW Ministry of Planning and Housing (Hoffman et al., 2019). Damage was found to be mainly on hob beams distributing forces between certain columns on levels 4 and 10. Panels resting on these hob beams and floor plates adjacent to the corresponding columns were also found to be damaged. In the final report, differential settlement of the building's footings and environmental factors such as heavy rainfall and high winds were ruled out, and issues with the structural design and construction of the building were declared as the main causes of structural damage. Similar to the Grenfell Tower case that is known as the epitome of the issues in the building construction and operation, the Opal Tower and Mascot Tower that had similar failures are known to be the catalyst for the NSW government to take action on required regulatory changes (Crommelin et al., 2021).

Procurement issues

Non-compliant structural design

Investigations revealed at least two areas of the as-built structure not complying with the relevant Australian Standard, AS 3600 Concrete Structures, and therefore, not satisfying the requirements of the National Construction Code Volume 1 (Hoffman et al., 2019). These areas coincide with the locations of the most serious damage at levels 4 and 10 of the building (ibid.). The strengths of the damaged hob beams at levels 4 and 10 did not meet the requirements of AS 3600-2009 (the operative version of the code at the time) to withstand the assumed design forces. Moreover, the provided tie-reinforcement for the hob beam was inadequate to resist the significant splitting forces (ibid.).

Non-compliance of the finalized structural design to the relevant Australian standards not only suggests lack of knowledge and experience of the design team, but also indicates the absence of adequate quality assurance and control systems that have allowed for such problems to go undetected throughout design and construction (Hanmer, 2020). It also points out the lack of adequate regulatory enforcement to ensure compliance of buildings with building standards (Bolton, 2018).

Construction issues

In addition to inadequate design, a number of construction issues have reportedly contributed to the structural damage to the building, where the construction differed from the design and/or standards.

Hoffman et al. (2019) found that, while according to the design drawing full grout coverage was expected between the hob beam and precast panel, during construction only the inner surface of approximately 50-70% of the joint width had been grouted. Partial grouting resulted in eccentric loads and additional bearing and bursting stresses on the hob beams. The cover concrete of the hob beams was also found to be inadequate and discontinued column bars were found to have encroached the cover zone. An electrical conduit was placed within the cover zone in the vicinity of the hob beam to column connection. Moreover, the precast panels which were designed to be manufactured 180mm thick to correspond to the thickness of the hob beam, were constructed 200mm thick overhanging the interface of the hob beam. Wrong size reinforcing bars were also placed in the horizontal direction of the bottom region of a panel, resulting in inadequate tensile capacity. No evidence of utilization of reinforcement crossties were found in the damaged hob beams during site inspections and in the construction photos. Additionally, the strength of the concrete used in construction of the hob beams might have been lower than expected. According to laboratory records, the 28-day strength of the concrete samples was 50 MPa, while 65 MPa concrete was ordered for supply.

Mismatch between the constructed building elements and the original design drawings further emphasizes the inadequacy of the quality assurance and control mechanisms. An example of this fragmented approach and mismatch is the contracting documents and views regarding the design strength of the hob beam concrete on level 4. This indicates deficiencies in documentation and communication of building specifications within the project team.

Procurement lessons to be learned

1. Laws and regulation: The majority of the problem in the case of Opal Tower (and Mascot Tower) can be associated with the regulatory enforcement as it does not provide enough accountability throughout the life-cycle of the building, and does not ensure effective workmanship and checking of construction compliance (Crommelin et al., 2021; Hoffman et al., 2019).
2. Standards and codes: Inadequate structural design is shown to be a major cause for the structural damage of the Opal Tower. Ensuring knowledge and experience of the design team as well as their familiarity with the relevant Australian standards can help avoid such problems in the future. Hoffman et al. (2019) suggest creation of a registry of engineers to ensure their competency including internationally benchmarked qualifications, minimum industry practice and experience, and currency of professional development.
3. Performance and operations: Part of the problem can be associated with the project delivery approach, i.e., design and build. Regulations should be in place to ensure that the design process is carried out by third-party competent design teams. Design and build methods must be restrained to the builders who can demonstrate the required expertise and necessary quality control processes in-house (Hanmer, 2020).
4. Quality assurance/Quality control: Rigorous quality assurance and control procedures need to be defined to avoid probable mistakes in design and construction. Different parties such as the design and engineering team, procurement team, and representatives of contractors need to be involved to ensure consistency of the design and construction with Australian codes and standards. The level of confidence in the quality procedures can be increased by involving third party registered engineers to certify the final designs, undertake onsite inspections during critical stages of construction, and approve changes to the critical components during construction.
5. Communication: Integrated documentation and communication procedures need to be in place to ensure a seamless flow of information and consistency of different project documents. Digital tools such as the ones supported by Building Information Models can help ensure access of all parties to the most up-to-date versions of their information needs. These platforms may also facilitate automatically detecting contradictions among documents (Zhang et al., 2020).

3.2.5 Channel Tunnel (1985-1994)

The idea for a tunnel joining France and England under the English Channel (La Manche in French) was famously considered by Napoleon in 1802. Technology and political will finally brought these plans to fruition in the late twentieth century. The Channel Tunnel, completed in 1994, was the largest private sector infrastructure project of the twentieth century. It comprised two 7.6m diameter rail tunnels and a 4.8m diameter service tunnel running approximately 50km beneath the Straits of Dover, plus all associated infrastructure and rolling stock. While the competition to build the tunnel was sponsored and initially organised by the French and UK governments, the project was built with no government guarantees – financing was left to the market.

The project was 19 months late and cost more than double the original estimate leading to major questions about the financial viability of the tunnel through the 1990s. The project was a technological success but a financial failure whereby each passenger who uses the service is heavily subsidized by the private investors who financed the project (Flyvbjerg, 2014).

The initial project structure

The overall structure of the tendering process was an exercise in optimism over substance with no clear project specification which led to poor project risk management and a lack of alignment in goals between the parties.

The British and French governments set up a competition to build, own and operate a fixed channel link. Tenders opened in April 1985 and the invited tenderers had only seven months to prepare their proposals. The two governments gave themselves only three months to evaluate the four submitted tenders which included proposals for various kinds of bridges and tunnels (Stannard, 1990).

Tender evaluation was done on the basis of financial and technical viability. The successful consortium of banks and construction companies was announced in late January 1986 with no consideration of their competence in ongoing operation of major infrastructure despite that being part of the scope. The winning consortium proposed a project to design, build, equip and commission the tunnel system over 4½ years to May 1993 at a cost of £4.87 billion. Ultimately the cost blew out to over £10 billion (Genus, 1997a).

The winning consortium established an entity called Eurotunnel to raise the finance for the project and a construction company called Trans-Manche Link (TML) which contracted with Eurotunnel for £2.66 billion to design, build and commission the full system by May 1993 (Shani, 1993). The contract was negotiated between the construction companies and the banks. The banks pushed hard for a lump sum contract as they believed this was a way to minimise their risk. From an engineering perspective, such an arrangement was not possible due to the significant uncertainties that remained at this early stage. The final contract included some aspects of target pricing, some lump sum components and some cost-plus elements.

It is now accepted that a more comprehensive planning stage and establishment of a clearer ongoing owner for the infrastructure would have avoided many of the later problems. Colin Kirkland, technical director of Eurotunnel from 1985 to 1991 later described this method of managing the overall project setup as ‘like releasing a mouse at a Christmas party – the reactions of all those affected are unpredictable and uncoordinated, and everybody believes that he knows what the end result will be’ (Kirkland, 1995).

Lack of a ‘client’

From the beginning, there was no clear ‘client’. It was part of the role of the successful consortium to create a client organisation. The adversarial nature of the contract led to major issues with trust and continuing poor management of project risk.

A fund-raising share issue in October 1986 was contingent on the project promoters, investors and building contractors giving up control of Eurotunnel. At this point, control moved to institutional investors and an independent Board so that Eurotunnel could transform from a financing agency of the contractors into an owner and eventually operator of the Tunnel. As such, Eurotunnel took over responsibility for project management functions and as the holder of the 55 year design, construction and operating concession (Genus, 1997a). By this time TML was well underway and they had no interest in supporting anything other than a weak client to oversee them. A former senior executive of Eurotunnel famously referred to the Tunnel contractual arrangement as being like a ‘polo mint’ (Genus, 1997b). Presumably he means having no heart or centre from which to drive activity.

As the project proceeded, several major areas of disagreement arose. A key point of dispute related to the contracted requirement for ‘optimization’ i.e., finding the best balance between capital and operating costs. Since

TML was responsible for capital cost and Eurotunnel was responsible for operating costs, the interests of the parties diverged significantly. In a contracting environment that also favoured a fast track approach of simultaneous design and construction and Eurocontrol's belated arrival on the scene, conflict was inevitable (Genus, 1997b).

A consequence of the structure of the project was the poor handling of the interface with the Intergovernmental Commission (IGC), the project's impartial regulatory and safety watchdog. IGC required major design changes on safety grounds as the project proceeded. Many of them were imposed after supplier contracts had been signed. TML made a series of claims against Eurotunnel who in turn made several claims against IGC.

Another problem was that the whole project benefit was contingent upon construction of high-speed land links to complete the transport route between Paris and London which the French government did but the UK did not for some time. This broader work to embed the Tunnel in a full operating system was another client responsibility that was done poorly in the initial stages because of the way that Eurotunnel came into existence.

Project culture

The winning consortium included 5 French firms and 5 British firms, leading to a necessarily multinational, multilingual workforce. Nearly 13,000 people worked directly on the construction of the tunnels (more than 100 million working hours) (Vandenbrouck, 1995). In the early stages of the work, there were effectively 2 separate projects operating at 2 different sites on either side of the Channel. Jack Lemley (CEO of TML from 1989 to 1993) notes that cultural differences were ignored in the early stages of the project but in the end 'differences in currency, language, culture and tradition, government attitudes, law and legal systems, professional practice and many others' had to be addressed (Lemley, 1995).

Dispute resolution

As described earlier, the banking consortium had a major influence on the contracting strategy, rolling everything into one contract with various ways of compensating for different aspects of the work. Separate contracts with requirements driven by the technical needs of the purchase (such as uncertainty/risk and expertise) would have led to easier project management and a more cost-effective outcome. A single contract made for an uncompetitive and adversarial relationship. TML, with their longer technical involvement meant that they always saw Eurotunnel attempts to manage them as interference. This culminated as a highly adversarial relationship between the parties and a 'winners and losers' mentality. Dispute resolution processes were triggered continually.

Project risks were not shared equitably. In the original contract, TML was responsible for only 30% of cost overruns to a maximum of 6% of overall cost. All other overruns were Eurotunnel's responsibility. This arrangement was renegotiated in 1990 to share the costs arising from unexpected engineering problems more fairly.

Both TML and Eurotunnel were restructured several times and made claims against each other as the project proceeded, leading to initiation of the formal dispute resolution clauses in the main contract. Dispute resolution was driven by each party seeking to minimise its financial liability, rather than sorting out the engineering solution first and then discussing who will pay – a more 'partnering' style of contracting.

The Channel tunnel project was successful overall in developing a major piece of transnational infrastructure. Having said that, multiple issues with the way in which procurement was organised led to very serious cost overruns which hold important lessons for other projects.

Procurement lessons to be learned

1. Poor overall planning meant that the tendering phase went ahead without a clear project scope and baseline specifications. The tendering phase of the project was also rushed, particularly given the enormous breadth of the scope of work from concept into operation of a fixed link. Ensure sufficient upfront effort on projects to define a clear scope and tender evaluation process.
2. The supply chain was poorly configured in at least two ways. Firstly, no-one had the authority or vision to effectively coordinate the actions of all the parties. There was no 'owner' in the early stages of the project other than financiers. A strong owner is needed to ensure that the purpose of the project remains the key priority throughout.

3. The other supply chain configuration issue was that despite the contractor scope being design, build and operate, the successful bidder was chosen without taking operating experience into account. There is a need to ensure that contractors are competent for all activities they are expected to undertake. If appropriate contractors cannot be found, the scope of work may need to be divided into smaller packages.
4. Another issue with scope and baseline specifications was that Eurotunnel activities were poorly linked into the overall rail network beyond the tunnels, particularly on the British side. There is a need for project structures to foster relationships with existing operations so that interfaces are well managed or project benefits may not be realisable.
5. Project risk management was driven by financial institutions who wrongly thought that pushing all financial risk onto the engineering companies was the best risk management strategy. Project risk management processes must be grounded in consideration of the engineering risks to project outcomes and how they are best managed including shared responsibility for residual risk.
6. The adversarial contract with inappropriate sharing of risks and unaligned project goals led to lack of trust between major parties and constant disputes. For complex projects, ‘partnering’ style contracts are preferred to align goals and share risk and reward.
7. Regulatory risk was poorly managed. IGC effectively acted as safety regulator for the project and insisted on late design changes which took both TML and Eurotunnel by surprise and were very costly. Responsibility for managing this relationship was not clearly defined in the contract. Responsibility for early engagement with regulators is critical so that requirements and a time frame for key reviews and approvals is established. Without this, potential expensive rework is possible.
8. Projects that involve team members from different nationalities working in different countries likely induce risks resulting from differences in legal systems, culture and tradition, disciplines, languages, ways of working and many others. Careful consideration must be given to improve an understanding of such issues in the conceptual stages of the project and throughout project execution. A focus on effective communication must be prioritized and maintained to address any cultural matters.

3.2.6 Demolition of the Royal Canberra Hospital (1997)

On 13 July 1997, thousands of people gathered on the foreshore of Lake Burley Griffin to watch the demolition by implosion of the old buildings of the Royal Canberra Hospital on Acton Peninsula as the event had been promoted as a public spectacle. When the demolition was triggered, a fragment was expelled from one of the corner columns of the Main Tower Block, instantly killing Katie Bender, a young spectator 430m away in the crowd. The inquest report following the accident detailed a number of factors contributing to the cause of death, including the incorrect use of explosives and insufficient site preparation, the failure to obtain advice or consultation from experts, and inadequate protective measures and testing (Madden, 1999).

The cause of failure

The inquest report into Katie's death by the Coroner, Mr Shane Madden, described the implosion project as a systemic failure with those involved failing to adequately comply with the standards and codes of practice as well as the requirements of contracts. While implosion, if carried out properly, is as safe as conventional methods of demolition, it is the use of this method by incompetent and inexperienced personnel that led to the death of Katie.

The responsibility for the safe conduct of the implosion project fell to the contractors and of those who employed and supervised them. The project director and manager were inadequately skilled for overseeing the task undertaken by the contractor and subcontractor. Their lack of relevant knowledge and experience resulted in inadequacies in assessing the suitability of the contractors for a specific task and the quality of the tenders, particularly in the implosion method. This enabled final decisions to be made months prior to the finalisation of the tender process without any critical examination or consultation of the demolition proposal which should have been carried out in a project of this kind (Healy, 2015).

Both the contractor and subcontractor were not sufficiently competent for a high dangerous task, resulting in failures in employing a correct methodology of implosion. These include using an excessive amount and a wrong type of explosives. Another factor is the failure to follow appropriate safety procedures, particularly protective measures on the site, such as using a steel backing plate instead of a soft backing cover like rubber. The contractor also made incorrect cuts following the engineer's negligent approval and placed explosives on the incorrect side to the building's steel columns, causing the blast to be directed at the spectators (Madden, 1999).

Another factor that contributed to the accident was a lack of supervision on the site by the engineer to ensure the approved method of cutting columns was complied with. The project also failed in obtaining expert advice from experienced structural engineers and independent explosives demolition specialists in the implosion process and method of demolition. Consultation with relevant experts to be independent of the contractors and project management team in accordance with the Demolition Code of Practice was missing (Madden, 1999).

Further, the actions and omissions of the ACT government bodies involved in the demolition project also contributed to its failure. A major failing of this project was that the inspectors from ACT government bodies permitted the implosion to proceed with the expectation that protective measures such as low bund walls and sandbags would exist on the site. The implosion could have been stopped by the inspectors in the form of a prohibition notice if they had adequately deliberated the safety of the reconfiguration of the blast. Noticeably, evidence showed that the inspectors were not safety inspectors and the project manager was fully aware of the fact that they did not have any qualification or expertise relevant to the demolition process.

However, while the Coroner's report concluded that the inspectors "failed to meet the standards… reasonably expected by a competent WorkCover inspector", it acknowledged that they did not contribute or have any direct connection to Katie's death. The roles and responsibilities of inspectors were not to double check the credentials and experience of the contractors selected or to act as a safety officer to those on the site, as required by the statutory duties (Madden, 1999).

Another government failing was the absence of consultation with relevant regulatory authorities and inappropriate decisions to promote the implosion as a public event that engaged thousands of spectators in a high-risk environment (Healy, 2015). This indicates a lack of adequate consideration to public safety and awareness of significant risks inherent in the implosion project.

Procurement lessons to be learned

1. The implosion project experienced deficiencies in appointing project leaders and selecting contractors. The project management team failed in advertising project tenders, providing adequate technical specifications and examining the contractors at the tender stage. The contracting, tender and selection processes need to be led by those with appropriate expertise and relevant experience to ensure high quality contracts are delivered.
2. Projects, particularly at high-risk levels, need to be undertaken by qualified contractors. In this implosion project, inspectors from regulatory agencies involved in the implementation stage assumed that demolition contractors were sufficiently qualified and experienced to be able to identify potential hazards. From a project management perspective, engaging independent examination and verification of the contractors' capacity prior to the appointment benefits the tender process and minimizes project risks induced by contractors' underperformance. In complex projects with high risks, contractor selection and auditing based on technical experience to ensure satisfactory performance is of paramount importance.
3. It is obvious that all professionals and government bodies involved in the project failed in estimating the level of risk exposure to public safety at all stages and in examining safety measures and protection throughout the project execution. A detailed risk management plan needs to be reflected in the application plan with input from relevant experts and approved by relevant authorities prior to the commencement of the work. In works encompassing unfamiliar risks like demolition projects, recommendations from independent experts with relevant expertise will give rise to overall interests of both the public and general work safety. These separate roles will ensure that there is no conflict of interest and expert advice will likely be acted upon the best interests of all involved.
4. A quality assurance (QA) system was not in place in this project. It needs to be active at all stages in high-risk projects. When lines of defence fail, for example, at the contractual arrangement stage, adequate QA procedures will minimise risks to ensure safe implementation of projects throughout their cycle.

3.2.7 I-90 Tunnel ceiling collapse (2007)

The Interstate 90 (I-90) Connector Tunnel was constructed as part of the Central Artery/Tunnel (CA/T) project in Boston, which was also known as the “Big Dig”. This project was one of the most costly and complex infrastructure projects in the US and was completed in 2006 at a final project cost in excess of US$ 14 billion. The project was intended to improve traffic flow in downtown Boston and was managed by Bechtel/Parsons Brinckerhoff (B/PB), a joint venture between two major engineering firms.

The I-90 Tunnel incident

The D Street portal, a section of the I-90 Connector Tunnel where the incident occurred, was opened to traffic in December 2000, and consisted of approximately 2,600 feet of cut-and-cover tunnel. The incident occurred at night on Monday, 10 July 2006. When a car was approaching the D Street portal, a section of the tunnel’s suspended concrete ceiling detached from the tunnel roof and fell onto the car. A total of approximately 26 tons of concrete and associated suspended components fell onto the car and the roadway. The driver of the car had minor injuries, but the passenger was fatally injured (National Transport Safety Board, 2007).

The D Street portal ceiling was installed by Modern Continental Construction Company, which was the contractor on the project. The suspended ceiling consisted of concrete panels and supporting steel framework. The ceiling was suspended from the tunnel roof by stainless steel anchors installed in place with epoxy adhesive (see Figure 5).

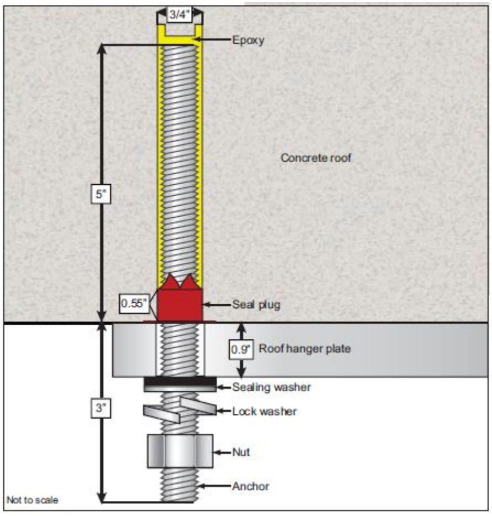

Figure 5. Adhesive anchor and roof hanger plate assembly (National Transport Safety Board, 2007, p. 9)

The National Transportation Safety Board (NTSB) undertook an investigation into the incident and found that all 20 anchors attaching ceiling support beam M1 to the tunnel roof pulled out and fell onto the roadway. Among the remaining 634 adhesive anchors supporting the D street portal ceiling, 161 were found to have measurable displacement, i.e., showing the evidence of having gradually pulled out of the roof under the sustained tension load (National Transport Safety Board, 2007).

Decisions to use the adhesive anchors

Gannett Fleming, the design consultant, originally proposed to use undercut anchors in the D Street portal in their design. However, B/PB rejected this proposal because they had problems when another contractor used undercut anchors on another project. Gannett Fleming continued to make the case for using the undercut anchors, explored various available alternatives and suggested to B/PB that undercut anchors were still considered as the best choice for this application. Once again, B/PB was not convinced, and maintained its directive not to use undercut anchors. Ultimately, Gannet Fleming accepted this directive and specified the use of adhesive anchors. The NTSB investigation found that this anchoring method was not necessarily inappropriate, but it was unusual in this application and neither Gannet Fleming nor B/PB took account of the long-term performance of the anchors. This is particularly an issue for adhesive anchors since polymer adhesives are known to deform under sustained loads. In practice, the responsibility for the overall fitness for purpose of the hanging system seems to have become blurred.

The epoxy

Regarding the installation of the tunnel ceiling, the NTSB established that all of the anchors had passed a short-term proof load test prior to the installation. NTSB determined that the design loads on each anchor "were well below the expected average ultimate load capacity published by the anchor supplier" (National Transport Safety Board, 2007, p. 85). The NTSB focused on investigating what had led to the failure of the epoxy and discovered ambiguities associated with the type and specification of epoxy used in the CA/T project.

The epoxy was supplied by the company Powers and was packaged as NRC-1000 Gold epoxy. It was available in in either Standard Set or Fast Set versions. The NSTB found that only Fast Set epoxy was packaged as NRC-1000 Gold epoxy, supplied to the CA/T project and subsequently used in the D Street portal. Post-accident testing requested by NTSB revealed that, while both the Fast Set and Standard Set formulations of the epoxy had similar performance in short-term load tests, they performed dramatically different under long-term load. Specifically, the Fast Set epoxy displayed significant displacement (creep) when subject to constant loading. The NTSB concluded that "the source of the anchor displacement that was found in the D Street portal tunnels and that precipitated the ceiling collapse was the poor creep resistance of the Power-Fast Fast Set epoxy used to install the anchors" (National Transport Safety Board, 2007, p. 90).

The question is how Modern Continental chose to use an epoxy formulation that did not fit the purpose of the application. The investigation revealed the contractor's lack of information about the epoxy and unethical behaviours of the sub-supplier who provided ambiguous, inadequate and misleading information about the product. The NTSB found no evidence that Modern Continental was provided with a choice or made a conscious decision to use one epoxy formulation over another. When Modern Continental contracted with Newman Renner Colony (the supplier of the adhesive anchoring system) to provide the Powers epoxy, the Fast Set epoxy formulation was the only one being offered by Powers (National Transport Safety Board, 2007).

Through reviewing relevant documents, NTSB discovered that the Power Fast Set epoxy was tested for creep performance in 1995 and 1996 and failed to meet the performance standard in both tests, thus it was recommended for short term application only (National Transport Safety Board, 2007). However, the information was not reflected in Powers' product documentation. NTSB discovered that in Powers' Fastening Systems Design Manual, the only difference mentioned between Standard Set and Fast Set epoxies was their respective gel and curing times. None of the product documentation provided by Powers to support the qualification of the NRC-1000 Gold epoxy indicated any difference in long-term performance between the two formulations. Power had clear evidence that the Fast Set epoxy was susceptible to creep and was therefore inappropriate for long-term tension loading and was aware that Modern Continental was using the product for long-term tension loads, no evidence suggested that Powers ever communicated with the contractor regarding which epoxy should be used in the D Street portal (National Transport Safety Board, 2007).

Specifications

The investigation undertaken by NTSB also revealed inappropriate specifications by the design consultant and a failure of expertise by both Gannett Fleming and B/PB when it comes to understanding possible failure modes of the anchoring system. Given the fact that all polymers are likely to deform under sustained load, the designers included no specifications in the contract regarding the long-term properties of the adhesive, no requirement of testing the adhesive for long-term performance, no consideration of the service life of the adhesive anchoring system relative to the expected life of the tunnel, and no provision for periodic inspections of the installed anchors (National Transport Safety Board, 2007). For the adhesive anchoring system, Gannett Fleming (the design consultant) only specified that the adhesive material should "remain unaffected by continuous humidity and by chemicals present in a vehicle exhaust type of air duct environment", without mentioning anything about the potential for creep in such materials and the need to verify the ability of the selected material in supporting long-term substantial tension loads (National Transport Safety Board, 2007, p. 91). The NTSB concluded that "Gannett Fleming and B/PB failed to account for the fact that polymer adhesives are susceptible to deformation (creep) under sustained load, with the result that they made no provision for ensuring the long-term, safe performance of the ceiling support anchoring system" (National Transport Safety Board, 2007, p. 86).

Procurement lessons to be learned

1. The project management consultant insisted on the use of adhesive anchors despite the design consultant continually making the case for using the undercut anchors. This illustrates the project management consultant's lack of deference to expertise. If the design consultant had used the undercut anchor system, they would have been more likely to make themselves aware of all the engineering limitations of such a system. It is important that decision makers do not make decisions based on the power and authority. Instead, they should defer to professionals with domain knowledge and skills.
2. Both the project management consultant and the design consultant failed to understand the failure mode being introduced into the system by the long-term use of adhesive anchors which are subject to creep under sustained load. This is potentially attributable to their lack of expertise with the adhesive. Due to the lack of expertise, the design consultant failed to develop effective specifications for the adhesive anchoring system by considering its long-term performance. Training and continuing professional development are necessary for designers and other practitioners to update their knowledge as well as keep up with new development and new products emerging in the industry.
3. The adhesive supplier failed to indicate the difference in long-term performance between the two types of epoxies in their product documentation, providing misleading information to purchasers. Product certification processes should seek evidence to verify information.

3.2.8 Berlin-Brandenburg Airport project failure (2011-2020)

Berlin Brandenburg Airport (BER) finally opened on 31 October 2020 after 29 years in the making with nine years of delays and more than double the initial estimated construction costs. Almost everything that could go wrong with this largest airport construction project in Europe went wrong, making the project a high-profile failure and a national embarrassment[9]. The failure has continued to damage the reputation of all actors involved, from planners to engineers, managers, politicians, and Germany as a whole (Fiedler & Wender, 2016).

Major causes of failures documented in several parliamentary hearings and full-scale investigations into this megaproject have so far included flaws in governance structure, deficiencies and mistakes in project planning, failures in construction and interface management (Fiedler & Wender, 2016).

History in the making

In May 1991, several months after the unification of Germany, the Berlin Brandenburg Airport holding company was founded for planning for the construction of a new airport in Germany's capital. The planning process for the development started shortly afterwards in early 1992. After several disputes, it took the company almost nine years to approve a tentative plan in late 2000 to open the airport in 2007[10]. However, this milestone and a number of further milestones established after that were unable to be achieved.

In 2003, the BER board decided to take over the planning and construction process, terminating the entire privatization process that was previously approved and taking the project forward under public sponsorship. In 2006, following disputes with residents and major issues over flawed construction cost calculations, physical work finally began at the new airport after 15 years of planning. However, the opening dates continued to be postponed owing to a series of technical difficulties, including persistent issues around the faulty fire safety system, construction fiascos, and allegations of corruption. During the time when a series of new opening deadlines continuously passed, many people including chairmen of the supervisory board and CEOs resigned or were dismissed.

Failure to appoint a general contractor

From 2003 to 2005, when the three governments, including the city of Berlin, the state of Brandenburg and the federal German government decided to change BER to a public project, they hired an experienced project manager from the private sector and Planungsgemeinschaft Flughafen Berlin Brandenburg International (pg bbi) which was a joint venture of architects as the general planner. While the roles of pg bbi were to undertake the design planning and review and supervise the detailed design and construction performance, the project failed to appoint a general contractor. This led to a series of major problems later as the responsibility for the detailed design remained with Flughafen Berlin Brandenburg GmbH (FBB), the developer of the project. FBB took the advice to break up the construction of the passenger terminal into 35 lots with the same number of tenders, which is a key contributor to the construction delays. Instead of overseeing one general contractor and contracting out construction and interface risks, FBB was in charge of the interface management with 35 contractors as well as all associated risks.

Deficiencies in project governance and expertise levels

The project also experienced deficiencies in governance structure and expertise at the management level. As of 2013, eight of the ten supervisory board members of FBB were politicians while the remaining two were a hotel consultant and a manager of the chamber of industry and commerce of a small city. A lack of expertise and experience in construction of the project supervisory board resulted in ineffective governance. In the case of the BER project, acquiring external expertise to compensate for the missing skills in project supervision and control

[9] https://www.dw.com/en/berlin-airport-the-five-biggest-mistakes/a-17740584
[10] https://www.dw.com/en/berlins-new-airport-a-potted-history/a-41813465

"was counterproductive as it further increased complexity and contributed to the disaster" (Fiedler & Wender, 2016).

The design process and change requests

As the project suffered major delays, FBB put effort into meeting a new targeted completion date in late 2011. Many different equipment and materials tenders proceeded before the detailed design was completed. The parallel design and construction processes led to significant interruptions in the construction due to mistakes or late delivery of design documents and constant design change requests. There were hundreds of change requests related to the fire safety system, including more than 300 requests for the smoke extraction services, leading to requirements to redesign and retest the entire installation.

FBB also ambitiously decided to redesign the terminal building to prepare for handling the newly developed A-380 Airbus plane with a capacity of 800 passengers (Fiedler & Wender, 2016). Later, it became clear that the A-380 would not use the BER airport in any future schedule but this design change necessitated significant changes in the smoke extraction system, further undermining its functionality. Almost 500 change requests were also made into the design of the passenger terminal by FBB until pg bbi's dismissal as a general planner.

Bad planning also resulted in hundreds of other issues being spawned in a chaotic rush to completion prior to the intended opening date in 2012. These included the flawed fire protection and smoke extraction systems, the over-burdened cable shafts, the overloaded roof over the terminal building, the weak cooling units potentially creating the threat of overheating cut-offs to the entire IT system, and the non-compliant material of the internal walls under fire protection regulations. Significant disruptions occurred as a result of planning errors and construction faults and ultimately caused an inevitable cost blowout and timetable delays.

Budget blowout and other issues

The financing in the BER project lacked transparency throughout the project. Neither the supervisory board nor the parliaments had provided a financing plan for the completion of the project. Figures were only available to the public once the delays started in 2012 and 2014. By late 2012 expenditures for the airport amounted to €4.3 billion, almost twice the original construction estimates and by 2015 the total costs reached €5.4 billion[11]. Additional needs for financial support to cover current costs and repair consequences continue[12].

A lack of a comprehensive governance framework in the project resulted in no project steering team and no mechanisms to monitor the management team. In addition, independent assurance by external parties was also absent from most of the project. Throughout the project, transparency was missing with parliaments and the public being uninformed.

Expertise and experience were not only missing at the management level but also of major concern at design and construction levels. Media reports revealed that the chief planner and designer of the fire safety system who was later admitted his lack of engineering qualifications was only a technical draftsman.

Procurement lessons to be learned

1. It is obvious from the BER project that expertise at all levels was either missing or inadequate. In large-scale complex projects like airport construction, relevant expertise and experience are requisite at both management and execution levels. Those who are responsible for decision-making need to have the capability and specific skills to understand project issues thoroughly, provide adequate levels of guidance and supervision and make informed decisions.
2. It would be more feasible to implement a large infrastructure project involving a general contractor, particularly in the context of complicated governance setups. This contractor should handle other subcontractors and be responsible for associated risks of the project execution. The BER project

[11] https://www.bloomberg.com/news/features/2015-07-23/how-berlin-s-futuristic-airport-became-a-6-billion-embarrassment
[12] https://www.n-tv.de/wirtschaft/BER-braucht-weitere-halbe-Milliarde-article22090324.html

became more complicated when the project management team had to oversee the interface and coordination of altogether 50 contractors and all technical and financial risks that could not be adequately allocated or transferred.

3. The project experienced inadequate planning, including insufficient time allocated prior to awarding contracts. Project planning and execution were in parallel with massive design change requests as a result of inadequate time for detailed planning and a rush to completion driven by the pressure to meet the targeted airport opening dates. ‘Planning fallacy’ about project delivery timelines occurred with project completion dates being underestimated. Time for planning should be sufficient to avoid unintended consequences.
4. Project assurance was missing mostly throughout the project planning and execution. In the BER case, many major problems accumulated that were only later investigated due to a lack of transparency. Independent assurance from external parties is indispensable to detect flaws in project management and performance.
5. No-one had the authority or vision to effectively coordinate the actions of all parties. A strong project owner is needed to ensure that the purpose of the project remains the key priority throughout.

3.2.9 NSW public transport failures

NSW trains too wide for tunnels

Transport for NSW let a major contract ($2.3 billion) for new rolling stock for the regional rail network to a South Korea manufacturer (O'Sullivan, 2018). Part way through the procurement process it became clear that the trains were wider than the existing rolling stock and so the normal safety clearance between the trains and some tunnels would be breached. In some cases, the trains are literally too wide to fit in tunnels in the existing system.

A key design specification for railway rolling stock is the cross-sectional dimensions of carriages which are set to maintain what is known as the 'kinematic envelope' i.e., the clearance all around the carriage that allows for rocking of vehicles and variations as carriages tilt when passing around bends in the line. The clearance is required to ensure a safety margin between rolling stock and fixed parts of the network such as tunnels and platforms. In the NSW regional network, eight older tunnels west of Katoomba are slightly smaller in diameter than the rest of the network, leading to a smaller sized carriage if the kinematic envelope is to be maintained.

Previous designs of rail carriages and locomotives have all accommodated the old tunnels, but it would seem that specification and risk assessment for procurement of the newest trains did not adequately take into consideration the different fixed facilities that the trains would encounter and so the specified kinematic envelope cannot be maintained in all cases.

The problems are to be fixed by a combination of relaxing safety standards and modifying fixed facilities. This will add two years to the current project, but a cost has not been released (Kimmorley, 2018). As of mid-2021, the new trains are not yet operational.

Sydney ferries too high for bridges

River Class ferries operated on Sydney Harbour have been criticised for similar sized-related problems. These new fleets of ferries built in Indonesia are too high to fit under some of the bridges on the Parramatta River. Passengers on the upper deck would have to move to the lower deck as the vessels pass those bridges (Calderwood, 2021).

In September 2017, Transport for NSW called for expression of interest from ferry builders for the new vessels for the Parramatta River route. However, the purchase was shelved as the bids were higher than expected (O'Sullivan, 2019). In 2019, the project went ahead and upon being awarded the contract, Transdev Sydney Ferries placed an order for 10 new ferries to be constructed in Indonesia (McCubbing, 2019).

In August 2020, solid asbestos was found in gaskets on four out of the ten new ferries during testing in Newcastle. The new ferries are also unsuitable for several specific operating regimes. The first new ferries which entered service in October 2021, more than a year later than scheduled, can only operate during daytime until a design flaw in the glass is fixed to reduce the glare in the wheelhouse at night. The existing fleet will continue to be used until the River Class vessels are available to roll out for night-time operations. Some of these ferries are not able to pull up to their usual wharf at Manly in very low tides. A spokesperson for the ferry operator Transdev stated that about 5% of the services were affected and options were being considered for a new gangway (Calderwood, 2021).

In January 2022, more than 40 defects were found across all of the new vessels which are undergoing major rectification work to their cabins so that they can operate in the dark[13].

No public domain information has yet been released as to why these problems have arisen so it is not clear at this stage whether the failures in risk management are primarily in specifications or whether the new ferries were

[13] https://www.smh.com.au/national/nsw/more-than-40-defects-discovered-in-new-sydney-harbour-ferries-20220116-p59omj.html

correctly specified and yet not delivered by the supplier. Various stakeholders are demanding an inquiry so more information may become available.

Procurement lessons to be learned

1. The specification for the new trains and ferries apparently did not take into account variations in operational requirements across the network. As such, expensive modifications will be required to run the new trains through the entire operating system. For the new fleet of ferries, commuters on the top deck would need to move downstairs for their safety. Specifications need to take into account all necessary variations in operating requirements.

This brief description of the cases is drawn from media reports. No doubt further lessons could be drawn if/when more details are released of why the procurement system has failed.

3.2.10 The CBD and South East Light Rail project (2011-2020)

Despite billions allocated to public transport infrastructure projects by the NSW Government, Sydney still has a long list of issues in public transport projects, from trains and trams to ferries. The decommissioning of the entire inner-west light rail fleet for up to 18 months is the latest among other public transport failures[14]. In October 2021, service was shut down due to cracks in the light rail vehicles, forcing thousands of commuters to use replacement buses. The trams on the newest line of the CSELR project through the CBD are different so they cannot be used to keep the inner-west route running.

The construction of the CSELR project has been characterised by a series of problems, including significant delays, higher costs with lower benefits than the approved business case, and a lawsuit in which the NSW Government has to pay more than half a billion dollars in compensation to Acciona Infrastructure Australia (Acciona), one of the design and construct contractors of the project.

Overview

The CSELR project is a large project with an estimated capital cost of $1.6 billion. This includes a 12-kilometre route with 19 stops from Circular Quay through the city to Kingsford and Randwick. Transport for NSW (TfNSW) started developing a strategic plan in 2011 and procuring major construction contracts in 2013. In late 2014, the PPP contract was signed with major modifications due to scope changes, leading to an increase in the capital cost budget to $2.1 billion. At the same time, the project benefits decreased from an estimated $4 billion in the 2013 business case to $3 billion in 2014. In 2015, ALTRAC Light Rail (ALTRAC) took responsibility for operating and maintaining the light rail services as part of a Public-Private Partnership (PPP) agreement. Major construction started in late 2015 and was expected to be completed in 2018 with services operating in early 2019. However, the project experienced major delays. The service was launched with the opening of the Randwick Line in December 2019 followed by the Kingsford Line in April 2020.

Planning and procurement

The 2016 Audit-General's performance audit report specified major problems around the way TfNSW managed the project in the period 2011-2014.

The project suffered from tight timeframes, an inadequate business case and poor governance in the planning stage. A dedicated project team was missing and the distinction between commissioning, assurance and delivery roles was unclear. The project design and scope of works were not finalised prior to the start of the tender process and the letting of the main PPP contracts. Consequently, bid prices increased and hence ongoing additional costs have been incurred. The increase of more than $500 million "was caused by mispricing and omission in the business case" (NSW Audit Office, 2016). Optimism occurred as capital costs were underestimated while benefits were lower than the business case due to increases in travel time assumptions deriving from changes in project scope.

TfNSW undertook an assurance approach that did not include independent gateway assurance reviews as is required for major infrastructure projects. Mandatory gateway reviews were skipped, leading to deficiencies in the project's governance arrangements being unresolved. Elements as part of a preliminary business case were missing, including rigorous analysis of options, costs, benefits, risks and sustainability issues, and the proposed governance framework.

Negotiations with contractors continued over design and scope changes, leading to increased project complexity due to major contract modifications. As the contract had been awarded, there was less pressure on the contractor to offer the best value prices for new or revised elements. The successful bidder (ALTRAC) proposed different design and scope from the reference design with significant changes in the design of the platform lengths and stops.

[14] https://www.abc.net.au/news/2021-11-14/sydney-transport-woes-despite-billions-spent-of-infrastructure/100618634

Potential conflict of interests between members of the pre-tender assurance review panel for the main contract also occurred during the procurement process but this was not recognised and addressed.

The performance audit report also noted inaccurate and untimely information released by TfNSW, which minimised the transparency and accountability of the project. These included incorrect estimates of costs in the business case which had been covered as “huge wins” offered by the preferred bidder. Further, TfNSW also did not disclose in a timely manner information on the reduced benefit-to-cost ratio of the project to the public, which was later acknowledged as an oversight.

A number of unresolved issues that increased the project risks and decreased value for money included: outstanding third-party agreements that affected the design and scope of works, planning consent conditions, early works contract scope, duration and status for handover to the contractor. The pre-tender assurance review did not adequately address the risk of interface management of two main contracts and potential risks of overlaps between the early works contractor package and the main works PPP package (NSW Audit Office, 2016).

Contractual modifications and dispute

The project not only suffered from significant delays and budget blowouts. There have also been unresolved claims for contractual modifications and undetermined penalties for delays. The relationship between TfNSW and Acciona deteriorated with a legal dispute arising between the parties over costs incurred from modifications to the line’s design. In 2018, Acciona commenced legal action against the NSW Government, further delaying construction work. Of the 31 zones along the CSELR route, work started late in 17 zones. In 2019, parties reached a settlement package with the government paying up to $576 million over the duration of the extended PPP term (Public Accountability Committee, 2019).

Project impacts

Concerns about excessive noise, dust and vibration caused by construction work along the light rail route, specifically night works, were raised with a large number of complaints received. Angst, distress and frustration among the community were reported and this was heightened by the project delays. The Public Accountability Committee of the NSW Parliament’s inquiry report highlighted a low level of involvement of the NSW Environment Protection Authority in managing and monitoring noise levels with very few warnings regarding potential breaches (Public Accountability Committee, 2019). In response to the Committee’s recommendation about expanding or independently establishing the Independent Environmental Representative (ER) to conduct noise monitoring, TfNSW refused to consider the recommendation, stating that expanding the role of the ER would not be necessary (Transport for NSW, 2019).

Another issue raised by residents was the adverse physical damage caused to their properties as a direct result of construction work and the process for claiming remediation. A lack of communication led to slow responses to property owners’ claims for damages (Public Accountability Committee, 2019). However, TfNSW stated that the responsibility to manage and resolve such claims would belong to ALTRAC and its contractor Acciona and TfNSW would rely on them to escalate any unresolved complaints (Transport for NSW, 2019).

The Committee’s report also emphasized financial losses and the significant impacts of the project on the physical and mental wellbeing of business owners who struggled since the start of construction with some having closed down. Small businesses were distressed “by the barricades, disruption in foot traffic and the severe loss of trade and goodwill” (Public Accountability Committee, 2019).

Procurement lessons to be learned

1. TfNSW followed project-specific planning and procurement processes to meet its preferred timelines without a preliminary business case and independent gateway assurance reviews. By departing from the established framework that provides assurance on the viability of projects throughout their life cycle, the project suffered from common problems including tight timeframes without justification, narrow scope and poor assessment of costs and benefits. Project planning and procurement must follow adequate framework and processes to ensure the maximised value for money.

2. Despite the complexity and significance of the project, the governance arrangements were weak in the planning stage with a lack of a dedicated project team and of well-defined roles and responsibilities. Governance structures need to be well set up with clear roles and responsibilities of all parties involved in the project.
3. Optimism bias (underestimated costs and overestimated benefits): TfNSW expected wide economic benefits of the project; however, the economic appraisal did not adequately take into account significant costs and disadvantages and quantify disruption impacts of construction. This along with inadequate planning increased the project costs significantly while expected benefits could not be attained. Project cost and benefit estimates should be based on the good ground with benchmarking against similar projects.
4. The project's assurance approach did not include independent gateway assurance reviews, leading to deficiencies in the project's governance arrangements being unresolved. Strong governance for procurement of large capital projects calls for independent review, a detailed probity framework, and extensive due diligence processes. Any potential perceived conflict of interest needs to be recognized and addressed to maintain confidence in procurement.

3.2.11 Loss of Space Shuttle Challenger (1986)

The loss of the space shuttle Challenger is a case study of procurement failure when it comes to both goods and services (Rogers, 1986; Vaughan, 1996). The shuttle itself has been designed and constructed by a wide range of specialist contractors chosen by the US National Aeronautical Space Administration (NASA). Each launch was treated by NASA as a separate project.

The failure

Originally scheduled for takeoff in December 1985, the launch of space shuttle mission 51-L using the vehicle Challenger had been delayed four times by a series of program issues and bad weather. When it finally launched on 28 January 1986, the vehicle exploded after only 73 seconds, killing the crew of seven astronauts. The loss resulted from failure of o-ring seals in a joint on the solid rocket motor that allowed hot gases to escape, impinging on the fuel tank and causing structural failure which then led to the shuttle breaking apart. The o-rings themselves failed due to the cold weather on the morning of the launch but the safety of the design of the joints that required these seals and the impact of weather on the o-ring performance had been the subject of discussion within the project team for some time.

The loss of Challenger highlights procurement issues with the shuttle components and with the relationship between Morton Thiokol (MT), the contractor responsible for the solid rocket boosters, and NASA.

The decision to launch

While there were systems in place that were designed to ensure that the best launch decision was made taking into account the views and expertise of contractors, these systems did not work well in this case. The lack of trust between MT and NASA at a working level meant that concerns raised by MT engineers were never communicated to decision makers. Poor risk management processes failed to draw management attention to escalating risks.

NASA had in place a formal process to decide if it was safe to go ahead with each mission. The Flight Readiness Review process comprised a four-stage process, starting with contractors formally certifying in writing the flight readiness of the elements for which they are responsible. Approvals trickle up through the system to stage 1 of the process comprising a conference of senior NASA representatives who make the final decision to go ahead.

Solid Rocket motor o-rings were assessed within NASA's system as a 'criticality 1' feature, a term denoting that failure could cause loss of life or loss of the shuttle. In risk management terms, this is essentially a consequence rating. The question then was how likely it was that a failure of this component might occur. The operating history of the space shuttle program indicated that o-rings were not as reliable as designed and were sometimes being eroded. Of particular concern to some MT engineers was the apparent correlation between low temperature and o-ring erosion.

Following observed damage to o-rings in other low temperature launches, this issue had been raised on multiple occasions in Flight Readiness Reviews for missions when ambient temperature was low but the formal advice was waived by a NASA middle manager at Level 3 in the Flight Readiness Review process. The concerns were never communicated to higher levels of management.

Regarding launch approval for flight 51-L specifically, weather forecasts suggested that the launch temperature on 28 January would be well below the experience base of the operating data. MT engineers raised specific concerns regarding the integrity of the o-rings given the forecast very cold temperature for the morning of the launch. They presented this data to NASA engineers on the evening before the launch with a recommendation not to launch. NASA disputed the analysis done by the MT engineers and famously demanded that the MT manager present 'take off his engineering hat and put on his management hat'. The MT manager later explained that he felt that he was being asked whether MT could prove that the shuttle would fail and if such proof was not available, then he should make a management decision that launch was acceptable. This is the reverse onus from that applied in the engineering analysis and that normally required by the flight readiness system. The MT manager felt that temperature effects were a concern but that the data was inconclusive. In this sense, MT could not prove that the shuttle would fail and under further pressure from NASA he gave MT's approval for launch to proceed. Again, these concerns were not escalated through the Flight Readiness system. Only MT's final signoff on readiness of the solid rocket motors for launch trickled up through the system.

On consideration of testimony of all relevant witnesses, the Rogers Review found that MT management gave approval for launch 'at the urging of [NASA] and contrary to the views of its engineers in order to accommodate a major customer.' (Rogers, 1986, pg 105)

Procurement of the solid rocket motor

Going back even further into the history of the shuttle design reveals earlier procurement issues linked to contractor selection, experience and expertise and quality assurance.

MT was one of four contractors to tender for design and manufacture of the solid rocket motors. The initial tender evaluation placed MT equal second on the list of preferred contractors (and last in terms of design capability) but a further review of the proposed designs by NASA noted that their jointed casing design would lead to the lowest costs in manufacturing and operation. Project cost was the key determining factor and MT were chosen as the successful tenderer.

The innovative jointed design was problematic from the beginning and exhibited problems during the test and certification stage but the issues were never adequately addressed. Performance issues with the o-rings were known by NASA from 1977 with the joints flexing in unexpected ways. This was despite tests not mimicking operational conditions. (Tests were conducted horizontally, rather than vertically which was the launch orientation.) Some NASA engineers expressed the view at that time that the design itself was unsafe and the joints requiring o-rings should be eliminated or redesigned. Despite this, the design was accepted for flight in 1980. Once in operation, as described above, persistent o-ring problems were seen with six consecutive launch constraint wavers issued prior to the 51-L mission. Commissioner Richard Feynman described the acceptance of escalating risk by both NASA and MT as 'a kind of Russian roulette' (Rogers, 1986, pg 149).

The Rogers Commission also noted that reductions in NASA's safety, reliability and quality assurance workforce had seriously limited capacity in these areas and further that the remaining personnel had been placed under the supervision of those whose activities they were supposed to check. As a result, the o-ring problems were not communicated to management until after the fatal flight.

Procurement lessons to be learned

1. Supply chain configuration was a serious problem. MT was chosen as the preferred contractor based on price, knowing that they were weaker technically than other bidders and yet once they were chosen there was no additional oversight of their technical weaknesses. There is a need to ensure information gained on supplier weaknesses (as well as strengths) is considered through the rest of the supply process.
2. QA/QC was lacking. The solid rocket motors were not tested in their operational orientation to some problems remained hidden until the operational phase. Integrity and performance tests must mimic operational conditions as far as possible.
3. Even when QA/QC was undertaken, the results were not acted on. Test rocket motor testing program indicated problems and yet work continued without any serious consideration of the need for redesign in order to meet schedule and cost constraints. In the end, it is better to make hard decisions, if needed, when testing indicates problems rather than continue and hope for the best.
4. Significant cultural issues meant that known problems were not addressed. People at both NASA and MT knew about the o-ring problem. It provides a strong reminder to encourage technical experts to speak up and to ensure that concerns are treated seriously. In the context of high reliability organizations, this is known as deference to expertise.
5. The risk management system was flawed in that NASA had assessed the consequence of failure of the solid rocket motor as the highest criticality in their technology management processes and yet they completely failed to collect and act on cumulating evidence that the likelihood of such a failure was significant. Project risk management linked to real world evidence of failures is important.

6. Trust issues impacted the effectiveness of risk management. Despite multiple formal systems in place to ensure risk was addressed in the context of launch decisions, news of the problems was never received by key decision makers. In the end, MT backed down rather than risk damage to their relationship with a key client. This indicates a lack of trust and a lack of common goals.
7. Further supply chain configuration issues meant that NASA’s oversight functions such as system safety and quality assurance were compromised because of reporting lines. It is critical to have sufficient skilled resources for safety and quality assurance and to give them sufficient independence for their voices to be heard at decision making levels of the organisation.

3.2.12 Boeing 737 MAX failure (2018)

On 29 October 2018, an Indonesian domestic flight operated by Lion Air crashed after pilots advised air traffic control that the aircraft was experiencing flight control, altitude and air speed issues. 189 people were killed. 157 people died on 10 March 2019 when another aircraft crashed in Ethiopia after experiencing similar control problems (KNKT, 2019). After the second accident, the problems were traced to Boeing's new aircraft - the 737 MAX.

Overview

Boeing 737 aircraft have a long flying history being first certified for commercial aviation use by the US Federal Aviation Administration (FAA) in 1967. The design of Boeing's 737 MAX aircraft was the 4th generation of 737 aircraft and was based on the previous model (737 Next Generation). On 8 March 2017, the FAA granted an amended type certificate to Boeing for the new design and the first aircraft went into service two months later. Seventeen months after that, the first of the two catastrophic crashes occurred.

The 737 MAX aircraft contained a new feature compared to previous models. The Manoeuvring Characteristics Augmentation System (MCAS) had the ability to trigger flight control movements independently of pilot action and could place the aircraft into a dangerous nose-down position. Inputs to the MCAS system came from the angle of attack (AOA) sensors externally mounted on either side of the aircraft fuselage. In both accident cases, faulty data from an AOA sensor triggered the MCAS system to incorrectly force the nose of the aircraft down. Pilots repeatedly struggled to regain control of the aircraft but were unsuccessful. In the Lion Air case, a similar incident had occurred with the same aircraft on the previous day, but the flight crew came up with an innovative method to control the aircraft (removing electrical power from the flight control that was incorrectly activated by MCAS) and the flight landed safely. The sensor problem was noted in the aircraft log, but the aircraft response and the innovative way around the problem were not recorded.

The US investigation into the accidents identified contributing causes as flawed technical design criteria, faulty assumptions about pilot response times and production pressures (Majority Staff of the Committee on Transportation and Infrastructure, 2020). In the context of this project, it is useful to consider Boeing as a supplier of complex, high-tech equipment to airlines with third party certification of the design of the equipment carried out by the US FAA on behalf of the airlines. In that framing of events, the accidents can be seen as procurement failure where a key supplier failed to deliver a fit-for-purpose product to the airlines.

Boeing and the US Department of Justice came to an agreement whereby prosecution has been deferred. Boeing agreed to pay over US$2.5 billion composed of a criminal penalty (i.e., fine), compensation to Boeing's airline customers and the cost of establishing a victims beneficiaries fund linked to the two crashes mentioned above (DoJ, 2021a). In addition, Boeing's chief test pilot at the time of the aircraft development and certification has recently (October 2021) been indicted for fraud, effectively for lying to the FAA (DoJ, 2021b)

Airline requirements

Applying a procurement lens to the disaster, the first key issue is that Boeing failed to supply the airlines with a fit-for-purpose product. Airlines had a choice of aircraft to purchase at that time. The 737 MAX was in direct competition with Airbus's A320neo aircraft. As a result, the contract arrangements pushed all schedule and cost risks of developing the new aircraft onto Boeing. The project team developing the aircraft was under enormous pressure to cut costs and maintain the project schedule for production of the new aircraft in order to meet airline requirements.

As part of the design of the new model, Boeing developed MCAS to address stability issues in certain flight conditions induced by the plane's new, larger engines, and their relative placement on the 737 MAX aircraft compared to earlier models. Despite the system's role in-flight stability, it was not declared a safety-critical system. The system also operated on a single input (an AOA sensor) which contravened Boeing's safety philosophy. Despite pilots not being told that the system operated in this way, Boeing assumed that pilots could quickly compensate for any potential malfunction.

More than that, AOA sensors are not new and previous 737 models had an alarm to indicate if AOA sensor readings disagree (i.e., if one sensor is faulty). This alarm was also part of the certified 737 MAX design but in fact it was not functional in the 737 MAX aircraft delivered to airlines, making it even more difficult for pilots to determine the nature of the problem if the MCAS kicked in incorrectly (Majority Staff of the Committee on Transportation and Infrastructure, 2020).

In summary, the malfunction of one of two AOA sensors had moved from something that would trigger an alert to something that would not trigger an alert but would threaten flight stability in completely unexpected ways. Risk management processes failed to ensure any of these issues were addressed.

FAA Certification

Boeing is a U.S.-based multinational corporation that designs, manufactures, and sells commercial airplanes to airlines worldwide. When an airline buys new aircraft, they are custom manufactured but the basic airworthiness of the design of the aircraft is not checked by each purchasing airline. Aircraft designs and operational requirements are certified. The US Federal Aviation Administration (FAA) prescribes minimum standards for the design and operation of aircraft and is responsible for ensuring compliance.

Much of the detailed work linked to certification is undertaken by Boeing Authorised Representatives (ARs), Boeing employees who represent the interests of the FAA and act on the FAA's behalf in validating aircraft systems and checking design compliance with FAA requirements. Such a system presents ARs with an inherent conflict of interest. The investigation found that ARs were aware of some of the design problems that contributed to the accidents and raised these with Boeing but the issues were not addressed and also not reported back to the FAA (Majority Staff of the Committee on Transportation and Infrastructure, 2020). In this way, QA/QC requirements for the new aircraft were fatally flawed.

Linked to certification is the level of pilot training required for the new aircraft. This is critical to schedule as Boeing's airline customers were permitted to fly the 737 MAX only after training requirements are approved by the FAA. Boeing technical pilots were responsible for providing the relevant information to the FAA. The investigation found that these individuals knew of the issues with the MCAS design and yet they deliberately hid this information from the FAA. As a result, the FAA deleted all information about MCAS from the final version of FAA documentation regarding operating the 737 MAX. In turn, aircraft manuals and pilot training materials lacked information about MCAS, and pilots flying the 737 MAX for Boeing's airline customers were not provided any information about MCAS in their manuals and training materials (DoJ, 2021a). As the US Department of Justice has said, 'Boeing chose profit over candour by concealing material information from the FAA concerning the operation of its 737 MAX airplane and engaging in an effort to cover up their deception.' (DoJ, 2021a) All this indicates a major cultural issue at Boeing and a failure to link the work to flight operations in the airlines.

The investigation also found many cases where FAA management had overruled a determination of their own technical experts when requested to do so by Boeing management. The FAA was completely 'captured' by Boeing and was not providing any degree of independent oversight. Consistent with this finding, the US Senate investigated aviation safety oversight following these accidents and received input from 57 whistle-blowers regarding failings at the FAA (Commerce Committee Majority Staff, 2020).

Procurement lessons to be learned

1. Contractual terms and conditions: Boeing were cutting corners in complying with their own safety systems due to schedule and cost pressures as a result of commercial competition between otherwise similar suppliers. In cases such as this, the potential for cutting corners to recoup costs by the successful supplier should be identified, assessed, and mitigated where possible, likely by additional inspection/audit activities.
2. The supply chain configuration separated Boeing's activities from actual airline operating pilots and their needs. Pilot training provided by Boeing failed to address key safety issues. Having operational personnel embedded in the design office would likely uncover this type of issue.
3. Given the structure and culture of the sector, operational input to the aircraft design was provided by Boeing technical pilots whose loyalty was to Boeing, rather than the airlines. They were actively involved

in hiding design problems from the FAA. This emphasises the importance of having operational input from those who will actually be operating new facilities.

4. QA/QC was not effectively provided through the regulatory system. FAA certification activities were significantly undertaken by individuals working in-house at Boeing, so they lacked any independence or power when problems arose. Arrangements with third party certifiers must be structured to ensure no conflict of interest either individually or organisationally. Further, Boeing lied to the FAA. Not everyone in business always behaves ethically. It is important to consider how important information can be independently verified.

3.2.13 The Myki ticketing system (2005-2014)

In 2002, Myki, development of a smartcard public transport ticketing system was planned to replace Melbourne's ageing Metcard system that would expire in 2007. An initial budget of almost $1 billion was approved in 2005 for the Myki project. However, since that time, this ICT-based project has experienced significant technical challenges, major delays in implementation and cost overruns. The project became the subject of public controversy.

Implementation of Myki

The Myki system was due to operate by July 2007 but the time taken for its design and implementation more than quadrupled from the original plan of two years, to in excess of nine years, while similar projects in the world had been implemented in shorter timeframes (e.g., the much simpler Oyster system in the UK took seven years to implement). This resulted in substantial unanticipated additional costs of approximately $550 million, an increase of more than 55% in the original budget of the project (Victorian Auditor-General's Office, 2015).

Compared to several smartcard systems in Perth, South East Queensland and London, Myki was the only smartcard ticketing system that integrated both metropolitan and regional areas and covered a wider range of functions as well as a complex range of ticketing fares. Since its roll out, the Myki system had encountered many operational issues, including slow card reader response times, intermittent technical failures and inaccurate data regarding patronage measurement. Among more than 5,000 complaints from public transport users about Myki performance between 2010-2014 reported by the Public Transport Ombudsman, overcharging was the most common issue followed by refunds and reimbursements.

Cause of failure and procurement issues

Reviews of the Myki implementation identified significant issues with the governance structure and contractual arrangements. The roles and responsibilities of key governance agencies were poorly defined, resulting in difficulties in determining which agency had overall accountability for the project and what different aspects of the project each agency was responsible for.

The project also experienced major issues associated with the initial contractual arrangements that undermined its viability. Specifically, the original Myki contractual agreement was too large, complex and hard to manage with over 13,000 pages, 40 schedules, 370 separate documents and 3,000 outcomes. Further, despite the complexity of the Myki system, the initial specification was poor, leading to more than 350 changes to the original specification during the development process (Parliament of Victoria, 2012). The procurement strategy included outcomes-based specification through an open architecture approach, resulting in difficulties in determining whether certain functional performance requirements were within or outside the contract's scope. This led to misunderstanding and ambiguities of the requirements and consequently disputes with the contractor about costs and priorities. The review from the Department of Treasury and Finance in 2014 also revealed that the contract did not include the flexibility to address contractor underperformance such as suspension or exit of the contract. The contractor had to manage outstanding build issues in parallel with the commencement of operations which compromised their capacity to meet agreed milestones and ultimately the project's delivery. As a result of insufficient understanding of the risks associated with ICT projects, a fixed tender approach was chosen which is not an appropriate procurement approach for such a risky ICT-enabled project like Myki.

As the expiration of the former Metcard was 2007, the Myki initial contract set an overly ambitious time frame for implementation of two years. This unrealistic delivery timeline led to the contractor consistently failing to meet milestones and subsequently resulted in major contractual amendments. Underestimation of the complexity of the project resulted in further cost overruns due to the need to keep the Metcard system operating in tandem with Myki for an extended period.

Reviews by the Victorian Ombudsman in 2011 and the Public Accounts and Estimates Committee in 2012 also highlighted the issue associated with relevant expertise required to manage ICT-enabled projects which are deemed to be high risk in terms of cost and time overruns. Inadequate ICT capability and capacity within commissioning agencies contributed to poor project management.

Procurement lessons to be learned

1. As the governance structure of key agencies was not well defined, there was disconnect in their responsibilities for public transport ticketing policy design and implementation. Ineffective communication and engagement between key parties occurred as a result of unclear responsibilities and roles. The initial planning must always define the governance structure well, including the roles and responsibilities of all parties involved to ensure effective coordination and communication and maximize transparency and accountability over the life cycle of the project.
2. The original contract was large, complex and outcome-based, leading to unclearly defined requirements of functional performance and consequently misunderstanding of the requirements by the contractor. This led to significant amendments to the original contract, and consequently major time and cost overruns. Contractual terms and conditions need to adequately clarify all requirements to achieve planned benefits and outcomes. Investing time to engage the contractor and other relevant parties in the beginning of contractual development is crucial to assure the clarity of contract requirements.
3. Project scope and planning: As a result of a poorly defined scope, substantial changes were needed to make to the original specifications and additional equipment requirements, incurring extra budget and delays. The project also suffered from inadequate planning, including a lack of appropriate benchmarking against similar projects implemented in other jurisdictions, in complexity, size, budget and time, in the initial contract. Learning experiences from other similar projects is essential to gain assurance about the feasibility of the project schedules and deliveries.
4. Timeframe for project planning: The initial delivery timeline for Myki was driven by a predetermined deadline which was the expiration of the former Metcard contract. The 'optimism bias' – the tendency to be over-optimistic about project timelines caused failures in meeting delivery milestones, poorly developed specifications and inadequate consideration of project risks. Project planning including implementation and delivery schedules needs to be developed based on the good ground not on deadlines of existing contract.
5. Experience and expertise: Part of the Myki project's issues was due to a lack of requisite competency and skills from the authority board to lead an ICT-enabled system like the Myki project, resulting in difficulties for board members to question details of the project. Not only contractor but project managers and external advisors are required to have relevant experience and expertise to manage the procurement or assist with oversight of technical aspects of the project. In the case of the Myki project, a contractor with intensive experience in ICT contracts and external advisors were later appointed to complement the capability and resources of the oversight and management team.

3.2.14 HMAS Westralia ship fire (1998)

The HMAS Westralia, a modified tanker and underway replenishment ship, had undergone six-weeks maintenance prior to its sailing on 5 May 1998. Members of the ship's company in conjunction with the Fleet Intermediate Maintenance Authority and the prime contractor, ADI Limited, were responsible for the maintenance work. This included the fitting of new flexible fuel hoses to the main engines which was undertaken by a subcontractor under ADI's direction.

At about 10.30 AM on 5 May 1998, one and a half hours after departure from Fleet Base West, when the ship was about 2.5 miles east of the Fairway Buoy in the Deepwater Channel, a huge fuel leak was found near Cylinder 9 of the port main engine with fuel spraying under pressure like a garden hose. The port main engine was shut down to allow repairs to be carried out and so personnel could set up fire-fighting equipment in the main machinery area to reduce the risk of ignition.

Only about five minutes after the fuel leak was seen, a fire broke out in the main machinery space and quickly became intense, destroying electrical cables on the deckhead above the main engines. The fire quickly caused thick black smoke and extreme heat to build up, making the atmosphere in the room inadequate to support life. It took two hours to extinguish the fire. Despite the fire-fighting efforts with external medical assistance and additional firefighting equipment from other ships and a helicopter, the crew was unable to save the midshipmen. Four young sailors died in the main machinery space as a result of carbon monoxide poisoning from smoke inhalation. It was the worst naval disaster in Australia in 34 years since the Melbourne-Voyager collision in 1964 that led to HMAS Voyager sinking with the loss of 82 among the 314 people aboard.

Cause of fire

The report of the Royal Australian Navy (RAN)'s Board of Inquiry (BOI) into the incident concluded that the fire "was caused by diesel fuel from a burst flexible hose spraying onto a hot engine component and then igniting" (Royal Australian Navy, 1998). The new flexible fuel hoses had replaced the original rigid pipes. Testing of the failed hose and other newly installed hoses clearly confirmed that the steel braiding wires had failed due to fatigue after less than 40 hours of operation. The failed hoses had approximately 50 adjacent wires in 5 to 7 braids fractured leaving the internal Teflon tube unsupported.

The source of the fatigue loading on the flexible fuel lines was most likely the action of the injector pump which causes pressure pulses in the supply and return lines of the low-pressure fuel system. The presence of these pulses was well known to the engine manufacturer and the International Maritime Organisation. However, there was no consultation with relevant experts by the contractor, subcontractor or Westralia's staff (Royal Australian Navy, 1998).

At the time when Westralia sailed, there was no sign of any inherent flaw in the flexible fuel lines. (Royal Australian Navy, 1998). The tension of the operating wires would only have been obvious to experts through close inspection. There was no apparent materiel deficiency that should have prevented the ship from sailing on the morning of 5 May 1998.

Procurement failure

The BOI report concluded that the new flexible fuel hoses fitted by a subcontractor during the maintenance period "were not properly designed and were unfit for the intended purpose". Further, the proper processes for organizing and carrying out the configuration change that led to the fitting of the flexible fuel hoses were bypassed, largely due to "ignorance and incompetence" of key personnel within RAN and ADI Limited (Royal Australian Navy, 1998). Specifically, the intended arrangements were not approved by the appropriate authorities and did not comply with Lloyd's Register of Shipping requirements. Even though the hoses could withstand the expected static system pressure, the arrangement was poorly engineered, and the design did not consider dynamic loads.

Although the key organisations involved in the flexible fuel hose fitting were all accredited to a quality standard, evidence showed that the quality assurance systems in place were either inadequate or inadequately implemented to prevent the provision of a non-conforming product. A lack of rigour by both external and internal quality auditing personnel was likely part of the problem.

When taking a broad view of the causes of the fire, the BOI indicated the weakness of the system in place. Not only the lack of knowledge of personnel involved but also the inadequacies associated with training and selection of key personnel failed to guarantee system safety. Key personnel both in RAN and ADI, the main contractor responsible for carrying out the maintenance work on HMAS Westralia were not adequately trained or qualified for the work they were responsible for. ADI failed to take necessary steps to supply safe and properly engineered products while RAN failed to obtain the shipping approval of the configuration change to maintain the ship's certification. In 2005, ADI was found guilty and charged due to breaching the Occupational Health and Safety (Commonwealth Employment) Act 1991 for its failure to properly oversee the work on HMAS Westralia's engines.

Procurement lessons to be learned

Following the accident, a number of allegations were raised formally and in the media against Australian government agencies and officers, leading to an internal investigation within the Department of Defence and an investigation by the Commonwealth Ombudsman to examine whether Defence had forewarnings of possible safety risk to the ship (Commonwealth Ombudsman, 2008). The report by the Ombudsman in 2008 indicated that the Defence was not aware of any concerns about the use of non-genuine and sub-standard spare parts in HMAS Westralia. Such concerns were not able to be "interpreted as any kind of warning of the circumstances" that contributed to the tragic fire (Commonwealth Ombudsman, 2008). The questions of who was responsible and who would hold accountable were left unanswered[15].

1. While the questions of responsibility and accountability remained, it is obvious from the accident that the procurement process failed from the purchase of unsuitable equipment to the poor design of the fitting of the flexible fuel hoses. The selection of suppliers (i.e., main contractor/subcontractors) was also part of the problem when they failed to provide safe product and quality work. It's crucial to set up necessary procedures to ensure the implementation of basic principles in procurement, including integrity, probity and accountability. The procurement process needs to take into account not only the value for money of the procured goods, services or works but also the safety principles, socio-economic and environmental objectives and the risks associated with the procurement.
2. The investigation report did not reveal if proper testing of the new flexible fuel hose had been undertaken during the ship's maintenance and prior to its sailing. However, it came to conclude that the hoses were only capable to withstand the static, not the dynamic system pressure. Adequate tests of the design in different conditions, as part of the QA/QC process, are always required and more importantly, performance testing must mimic operational conditions.
3. The configuration management process was a systemic failure as steps required to warrant safety were missing. Not only the formal process of the configuration change but also the quality management systems were either bypassed or inadequately implemented. Contracting an accredited external organisation for independent auditing will enable defects to be detected or minimised, if missed by the internal quality assurance process, and reduce possible conflict.
4. The failure of the maintenance work indicated a lack of competency of key personnel of both suppliers and operators. It is important to ensure qualified and experienced main contractor and subcontractors are selected, and to appoint competent personnel and provide adequate training to be capable of the responsibilities placed on them. The whole process needs to be implemented in a transparent and accountable manner to avoid procurement failures.

[15] Book reviews, "*Fire at Sea: HMAS Westralia 1998*" by Kathryn Spurling, 2018 https://navalinstitute.com.au/12032-2/

3.2.15 South Korean nuclear reactor shutdown (2013)

In May 2013, the Government of South Korea announced suspension of the operations of two nuclear reactors and extended shutdown of a third one to replace parts that were supplied using fake certificates (Cho, 2013). At the time, nuclear power plants supplied more than 35% of the electricity needs of the nation. As a result of this shutdown, the Ministry of Trades, Industry, and Energy expressed concerns about unprecedented electricity supply shortages during the summer due to the reactors being halted (Aljazeera, 2013).

Procurement issues

An investigation by the Korea Institute for Nuclear Safety revealed falsification of 2114 test reports in the period from 2003 to 2012 by material suppliers and equipment manufacturers. Moreover, during the period from 1996 to 2012, 62 equipment qualification documents had been falsified by testing entities. Further investigation of 101 companies revealed extensive illegal activities including bribery, limiting competition in bidding, and accepting parts with fraudulent certificates (Andrews-Speed, 2020). As a result, 100 individuals including people from Korea Electric Power Corporation (KEPCO) that is the operator of the nation's nuclear reactors, Korea Hydro and Nuclear Power Corporation (KHNP), parts suppliers, and certifiers were indicted (Wise International, 2013).

The shutdown of the two reactors in 2013 was due to concerns over falsified test reports for installed safety-related control cables (IAEA, 2019). These cables were manufactured by a Korean supplier, JS Cable, following KHNP's decision to procure safety cables from domestic suppliers for the first time in 2004. JS Cable submitted a bid to KEPCO Engineering and Construction (KEPCO E&C), a subsidiary of KEPCO, despite lacking the necessary capabilities to manufacture the cables to the required standards. Saehan TEP, which was chosen by JS Cables to test the cables, outsourced the testing to a Canadian firm, RCM Technologies (RCMT). RCMT reported the results of the testing as unsatisfactory, however, upon the instruction of KHNP to make the results acceptable, KEPCO E&C, JS Cable, and Saehan TEP decided to manipulate the test results rather than modifying the equipment (Andrews-Speed, 2020).

Widespread and systematic supply chain corruption was facilitated by the monopolistic structure of Korea's nuclear power industry, as well as close ties between the politicians, government, state-owned enterprises, and large family-owned conglomerates. The situation was exacerbated by the organizational culture of KEPCO and its subsidiaries requiring conformity, insufficient and ineffective regulatory infrastructures, and a generally low standard of personal and corporate ethics (Andrews-Speed, 2020).

Procurement lessons to be learned

1. Quality assurance/quality control: The corruption in Korean nuclear supply chain first came to light in 2012 after KHNP received information from outside the organization concerning problems with the supply chain (Kim, 2019). This observation highlights the ineffectiveness of the internal control mechanisms that were supposed to prevent and identify misbehavior. Continual reviews of these internal control mechanisms, preferably by third-party organizations, can help avoid these problems. Moreover, encouraging and protecting whistle blowers to report instances of suspicious and potentially corruptive activities can provide additional external safety mechanisms to prevent future instances.

2. Supplier behavior: Systematic corruption in the supply chain was facilitated by the monopolistic structure of the industry and the close relationships between government officials, politicians, and enterprises. Retired politicians and government officials were involved in the management of the relevant business association and companies, reinforcing an informal network of connections between these companies and government organization. Appointment of board members and senior managers of organizations such as KEPCO has been politically influenced. Regulatory action to restructure the industry and introduce more transparent and democratized procedures to save the interest of public can be helpful in this regard. The Korean Ministry of Trade, Industry and Energy issued new rules governing procurement at KHNP. For example, senior managers cannot leave KHNP to join supplier (Andrews-Speed, 2020).

3. Supply chain configuration: At least in the case of the safety cables mentioned above, there seems to be persistence on KHNP's part to procure goods and services domestically without ensuring the technological and managerial maturity of the local suppliers. The contract was then awarded to a vendor incapable of manufacturing the parts to the required standards. Transparent policies regarding the sources of procurement considering the potential of domestic suppliers as well as objective tender evaluation and selection mechanisms should be in place avoid similar issues.

4. Cultural issues: Personal and corporate ethics should be emphasized to reinforce internal mechanisms to avoid corruptive behavior. Cultural aspects should be revisited to resolve issues with conformity, excessive respect to superiors, and unwillingness to challenge their decisions that are mostly cultural and behavioral in nature (Andrews-Speed, 2020).

3.2.16 Cabin Creek Hydroelectric Plant fire (2007)

This case is primarily about procurement of services and the need to assess competency of contractors and supervise them effectively.

The failure

On 2 October 2007 a flash fire inside a tunnel that was being recoated with epoxy killed five workers and injured three more. The work was being undertaken at Xcel Energy's hydroelectric plant in a remote mountain location in Colorado. The work location had only a single point of egress and the initial fire spread rapidly to buckets of solvent and substantial amounts of epoxy stored on location inside the tunnel. The workers who died were trapped and died from smoke inhalation.

The investigation by the US Chemical Safety Board found that inadequate contractor selection and oversight contributed to the incident (CSB, 2010).

Contractor selection and supervision

The workers who died were employed by RPI. RPI were known by Xcel to have a poor safety record which should have meant that their tender for the coating work was rejected. Instead, they were awarded the contract based on lowest price. This is despite another contractor being judged best from a technical and quality perspective. As a result of the known safety issues, the RPI contract included a specific clause stating that their safety performance would be closely monitored.

The work proceeded on that basis but no safety audits of RPI's activities were undertaken. In the weeks prior to the incident, Xcel managers became aware of several significant safety breaches by RPI including one recordable injury. Despite this, no action was taken.

After the incident, the CBS investigation found that the majority of RPI employees working at Cabin Creek had not received comprehensive formal safety training; effective training on company policies; or site-specific instruction addressing confined space safety, the safe handling of flammable liquids, the hazard of static discharge, emergency response and rescue, and fire prevention.

Procurement lessons to be learned

1. Supply chain configuration: RPI were selected to do the work based on price despite known safety performance problems. Companies with poor safety records should not be invited to tender. Once the decision was made to use a contractor with a poor safety record, the planned performance monitoring by the client never took place. All contractors should be subject to appropriate safety auditing to ensure performance is satisfactory.

3.2.17 Explosion at Shell Moerdijk Petrochemical Plant (2014)

This case is primarily about procurement of goods and the need to be very aware of any change to the specification of purchased items.

The failure

On 3 June 2014 an unexpected chemical reaction took place in a reactor vessel in the propylene oxide-styrene monomer plant. The system overpressured and the reactor exploded sending large debris up to 250m and smaller item up to 800m. The explosion was heard 20km away. Two operators were nearby and were injured by the blast wave and burning catalyst pellets. Smoke for the fire that followed covered adjacent local residential areas triggering local crisis management arrangements. Subsequent studies showed no offsite smoke impact on health in the local area.

Catalyst purchasing

The reactor system was being put back in service after maintenance at the time of the incident. In accordance with well established procedures, ethylbenzene was being used to heat the reactor contents. Tests conducted in 1977 when the original system was designed had shown that heating the catalyst bed in this way did not cause any unexpected reactions. This finding was assumed to hold through subsequent decades despite changes to the system including, critically, a change to the catalyst type.

A new catalyst was selected for use in 1999 which was less safe in use with ethylbenzene although this was not recognised at the time. In 2011, the catalyst manufacturer changes its production process resulting in new chromium impurities being introduced into the catalyst. This information was included in Safety Information Sheets provided to Shell after 2011 but not specifically highlighted discussed (Leveson, 2017). These two factors combined meant that the catalyst was safe to use in normal operations but a runaway reaction was possible when the catalyst was exposed to hot ethylbenzene.

Procurement lessons to be learned

1. A critical change was made in a supplied item (catalyst) without the change being assessed for the safety implications. Purchasers need to have a system in place to identify changes to routinely supplied items so that all implications can be assessed.

3.2.18 Hawaii fireworks disposal explosion and fire (2011)

This case is primarily about procurement of services and the need to assess competency of contractors.

The failure

On 8 April 2011, an explosion and fire occurred at a magazine that stored explosive materials resulting in the deaths of five workers. The workers were employed by DEI. They had been disassembling fireworks for disposal. The process they followed involved disassembling each firework into its component parts and accumulating the components, including explosive components. They were doing this work outdoors. Just prior to the incident, it started to rain so the materials and various metal and plastic objects being used by the workers were moved just inside the entrance to the magazine where explosive material were usually stored. This created the conditions for a mass explosion i.e., the entire load exploded simultaneously (CSB, 2013).

Contractor selection and supervision

DEI is a small firm whose primary business is storing unexploded ordnance on behalf of the US government. In early 2010, they were awarded a government contract to dispose of fireworks seized by customs officials in Hawaii. DEI was awarded the contract because, at the time, they were already storing the seized fireworks and their bid was assessed as the best overall value for money. DEI had no prior experience in fireworks disposal but this was not known to government procurement personnel nor was it uncovered during the procurement process.

Before disposing of the initial batch of fireworks in the first half of 2010, DEI had produced a risk assessment and a procedure for the disposal activity both of which were submitted to the relevant government agency. No-one at the agency had the technical skills to evaluate the quality of the work done and no feedback was provided. Due to minor operational problems with the disposal, the procedure was modified on several occasions and each time submitted to the government agency with no feedback received. The risk assessment was never updated and did not consider hazards associated with disassembly as was occurring by the time of the incident.

Procurement lessons to be learned

1. DEI was chosen as the successful contractor for an inherently hazardous task based entirely on commercial criteria. Contractor selection criteria must take into account technical experience when complex, hazardous tasks are involved.

2. DEI submitted technical documents to the government agency for review, but no-one had the technical skills to evaluate them. This further blurred responsibility for safety. Responsibilities must be clearly defined and those responsible must be competent.

3. DEI changed their fireworks handling procedures and again submitted them to the government agency for review but no-one with the appropriate skills looked at them. This illustrates the need for adequate management of change regarding the way in which hazardous tasks are being performed and again a clear delineation of responsibility.

3.2.19 Buncefield Tank Farm fire (2005)

The immediate trigger for the December 2005 catastrophe at the Buncefield oil storage depot in the UK was a large petrol storage tank that overflowed whilst it was being filled from a pipeline. The magnitude of the resultant vapour explosion was much greater than anyone knew was possible. Houses close to the terminal were destroyed and buildings as far as 8km away had windows broken. Forty-three people received minor injuries (but there were no fatalities). Over 20 large storage tanks on the site were destroyed in the subsequent fire which burned for five days. There was also significant damage to the adjacent industrial estate and interruption to aviation fuel supplies in the UK. The response involved over 1000 emergency services personnel (Hayes & Maslen, 2018).

The failure

Hertfordshire Oil Storage Ltd (HOSL) operated part of the Buncefield site. Tank 912 was being filled with unleaded petrol from a pipeline. The tank was overfilled because the tank gauging system was not working and the independent high-level system in place failed to shut off the supply to the tank. Petrol continued to flow from the top of the tank into the surrounding bund and a large vapour cloud formed. At 6am on Sunday 11 December 2005 the first explosion occurred likely ignited by traffic in a nearby carpark.

The Buncefield fire highlights procurement issues with the tank level instrumentation where the operation of a key safety device was compromised by a poor design and lack of communication along the supply chain.

The independent high-level switch

The high-level switch that failed to protect the tank has been supplied by a company called TAV Engineering in July 2004. The switch design allowed for some functionality to be routinely tested but the design also meant that it was easy for the switch to be left in a non-functioning state after such tests had been performed. A padlock was used to lock a lever into the 'operational' position. The padlock was to be removed for testing to allow the test lever to be moved and then reinstated to ensure that the test lever did not interfere with operation of the switch. Without the padlock in place there was no guarantee that the switch was functional. This is not a good design for a safety-critical instrument. TAV were aware that the switch was to be used in a safety-critical application but they chose not to modify the design (COMAH, 2011). The switch was replacing a model that did not include this padlock design.

The switch was part of an overall tank instrumentation package designed by Motherwell Control Systems. Motherwell engineers did not understand the criticality of the lever position or the padlock seeing it only as an anti-tampering device. TAV did not tell them and they did not ask, despite the safety-critical nature of the switch. The subsequent investigation criticised Motherwell's actions as follows:

- *'The process for ascertaining and then specifying the requirements of switches they supplied and/or installed was not adequate.*
- *They did not obtain the necessary data from the manufacturer and it follows that they did not provide such data to their customers.*
- *They did not understand the vulnerabilities of the switch or the function of the padlock.*
- *There was a reliance on TAV, which was not justified given the lack of information provided and the critical role that Motherwell had in installing safety-critical equipment.'* (COMAH, 2011, pg 14)

HOSL was also criticised for failing to provide sufficient oversight of the ordering, installation and testing procedures (COMAH, 2011). The switch was tested periodically but operational personnel were not aware that the padlock needed to be put in place in order to hold the test lever in the correct position for the device to perform its safety-critical function. COMAH also criticised aspects of the contractual relationship between HOSL and Motherwell, saying 'Where contractors are engaged to carry out work upon which the safety of many and much depends, something more rigorous than the evident casual relationship with Motherwell was called for:

- *There should have been a formal contract in place clarifying the expectations inherent in safety-critical work.*
- *There should have been an effective system of reporting and recording all significant faults and their resolution. This system should have been understood and implemented by both contractual partners.*
- *Reliable and up-to-date specifications of what was in place and what was required should have been provided.*
- *Critically, in respect of the replacement of the IHLS switches in 2004, there should have been a formal 'management of change' process. This typically would have included an engineering assessment of the benefits and disadvantages of any such change, and a consideration of what changes in procedures (e.g., in testing) would be necessary as a result.* ' (COMAH, 2011, pg 20)

Procurement lessons to be learned

1. Contractual terms and conditions: HOSL, Motherwell and TAV had informal arrangements in place for providing safety-critical equipment and as a result, things were missed. No clear vendor data was supplied for the safety-critical items. Formal arrangements must be in place where safety-critical equipment is to be provided to ensure that requirements and responsibilities are clear. Vendor data on key items is critical.
2. The replacement high level switch was designed differently to the one it was replacing and yet the safety impact of the differences was not assessed. Effective 'management of change' is important when procuring replacement items.
3. No explicit specification was provided regarding the new high-level system. Clear specifications for safety-critical equipment must be mandatory.

3.2.20 Summary of lessons learned from major procurement failures

The lessons taken from each failure case can be summarised using the risk source taxonomy developed in Section 3.1. Table 12 shows the occurrence of the four categories of risk across the nineteen incidents reviewed. It also shows the proportion of lessons to be learned divided across the same four categories. It is clear that supply chain coordination and management issues occur most frequently.

Table 12. Lessons from failure cases by risk category

Category	Occurrence in cases		Proportion of risk sources	
Supply chain coordination and management	11/19	58%	54/73	74%
Suppliers	5/19	26%	5/73	7%
External environment	5/19	26%	5/73	7%
Trust and cooperation	9/19	47%	9/73	12%

As shown in Table 12, we have identified 73 sources of risk and associated practice lessons to be learned from the nineteen procurement failures described above. Of those, 54 relate to the first risk category, supply chain coordination and management. The most common risk sources within that category are described below. Project identifying numbers refer to Table 11.

Eleven of the nineteen incidents were partly caused by issues with supply chain configuration i.e., the organizations included in the supply chain and the formal structures that link them. In most cases, this relates to the selection of a supplier that was not suited to provide the goods/services required. In some cases, it was because there was no effective prequalification system in place (2, 6, 13, 15). In other cases, it was because a supplier with marginal capability in relevant areas was chosen on the basis of low cost, but no additional measures were put in place to ensure that a suitable quality was maintained (11, 16, 18). Another supply chain configuration issue common to several failure cases is a poor link from procurement activities into ongoing operations so failures occurred at the end of the project when this gap was uncovered (5, 12). Other interface coordination issues arose in four cases – in one case the supply chain was configured so that oversight functions reported to those that their activities were meant to check, meaning that no action was taken when problems arose (11). One project suffered as responsibilities were not clearly defined between different work groups (3), and in the other two cases there was no effective construction management contractor, so no one was responsible for managing the interfaces between multiple smaller pieces of work (5, 8).

QA/QC issues also contributed to ten of the nineteen incidents. Poor testing (usually testing conditions not matching service conditions) (11, 14), lack of independent inspection (12), fraudulent test certificates (15), product substitution (1, 2), gaps in QA scopes (3, 4, 6, 18) and poor links from adverse QA results back into project decision making (11) are the key themes.

For seven of the failure cases, lack of experience and/or expertise within the project team was a significant causal factor. For several projects, this was an issue at several levels, meaning that the supply chain was poorly managed and there was no effective governance/supervision to detect and correct the problem (1, 2, 6, 8, 13, 14).

Six of the causes linked to supply chain coordination and management are about scope and baseline specifications. In most cases, key information was missing from scope and specification documentation (1, 7, 13, 19), particularly critical contexts such as interfaces with existing systems (5, 9).

Moving on to the other three categories in the risk taxonomy, the analysis of failure cases revealed five cases where causal factors were directly linked to suppliers. This might seem surprisingly low, but as noted above selecting the wrong supplier or not supervising suppliers appropriately are classified as supply chain coordination and management issues, rather than a supplier problem per se. Three supplier behavior issues were noted, all related to providing false or misleading information (test certificates, product data) (2, 7, 15). Two performance issues were noted – both related to constructed facilities that did not meet the required specification (3, 4).

Five of the nineteen cases also demonstrated a connection to external risk factors that became contributing causes. Four of these relate to legislation. In some sectors, legislated inspections form part of the risk governance process and in three failure cases, these systems failed with statutory inspections failing to reveal significant problems (1, 2, 4). In the fourth case, the project experienced delays because of a lack of appropriate engagement with the relevant regulator (5).

Trust and cooperation issues between organizations along the supply chain were flagged as contributing causes in nine of the nineteen failure cases. Common factors include lack of common goals (3) brought about by adversarial contracting arrangements (5) or inappropriate organizational structures/reporting lines (12). In some cases, this leaves known risks unaddressed as people are afraid to speak up (7, 11). A low standard of professional ethics was an issue in two cases (1, 15).

There are a small number of causal factors identified that do not fit into the risk taxonomy drawn from the literature. They fall into two areas. Firstly, for three of the case studies of procurement failure in an operational environment (17, 18, 19), management of change systems failed, effectively meaning that the wrong item was purchased. In three other cases (8, 10, 13), failures in overall project governance, particularly in the planning stage, meant that procurement problems arose and went unaddressed.

These failure cases provide input into later stages of the project but they may be directly useful to industry in their current form. Experienced professionals learn best by considering cases and the report provides nineteen examples of procurement failures that an provide the basis for discussion to reflect on current procurement practices and the potential for the same weaknesses to be present in any specific set of procurement practices.

3.3 Published procurement guidance

The final stage of the literature review is to identify and summarise lessons on risk management in procurement from published guidance material on major projects procurement. A review of available literature shows a wide range of relevant guidance material is available including:

- Several reports on procurement best practice published in the UK in the wake of the Grenfell Tower disaster
- Guidance produced by several Australian state governments regarding best practice in public sector procurement for major projects
- Material published by international organisations such as the World Bank and the OECD
- Guidance on major project dispute resolution.

Most of this material is not framed as being about management of risk, but rather principles of good/best practice in procurement. Nevertheless, much of what is provided is useful in considering risks to successful procurement and how to manage then effectively. A range of these publications is summarised below drawing out what each organisation sees as the main risks to successful procurement and how these risks should be controlled.

3.3.1 The UK Construction Playbook

In December 2020, the UK government published a new set of guidance material on sourcing and contracting public works projects and programs called The Construction Playbook (HM Government, 2020). The Introduction indicates that the new guide is part of a major push for improvements in public procurement for major projects by getting things right at the start. It is noted that 'successful project initiation can take more time at the start but this will be repaid many times over in delivery.' (HM Government, 2020, p. 2).

The guide focuses on three cross cutting principles – health, safety and wellbeing, building safety and build back greener.

Key points made in the guide are as follows, divided into five lifecycle stages. Consistent with the framing of the guide, by far the majority of the ley points relate to preparation and planning.

- Preparation and Planning
    - Publish lists of upcoming commercial opportunities so suppliers understand likely future demand for services across government. Engage with the Infrastructure and Projects Authority to provide appropriate information.

    - Assess the health and capability of the market you will be dealing with for all projects and programmes regularly – consider how you can take advantage of innovative approaches, encourage new or potential market entrants, and take action to address any concerns.

    - Review future projects and programmes regularly (at least quarterly) to identify opportunities to bring appropriate work together into portfolios and leverage economies of scale to drive investment into new technologies and Modern Methods of Construction (MMC).

    - Develop an organisational strategy to aggregating and standardising demand and driving the adoption of MMC.

    - Engage the supply chain to set realistic targets for the use of MMC and ensure that they possess the capability to report on the required metrics.

    - Meet and contract for the standards set out by the UK Building Information Management (BIM) Framework.

    - Consider the use of product platforms comprising standardised and interoperable components and assemblies.

    - Engage early with the market and be ready to demonstrate in the business case that your proposals have been informed by both your market health and capability assessment and feedback from potential suppliers including Small and Medium-sized Enterprises (SMEs) and Voluntary, Community and Social Enterprises (VCSEs).

  - All public works projects should contract for early supply chain involvement (ESI).
  - Appropriate, clear and efficient specifications are a critical factor in the overall timely and cost-effective delivery of projects. Specifications should focus on a whole life value perspective, and align with the government's wider economic, social and environmental priorities and commitments.
  - Embed a requirement for suppliers to identify and use a quality planning process in the delivery of capital projects and programmes, and familiarise contract management teams with quality processes.
  - Good approvals processes should be consistent, transparent and streamlined to enable effective decision-making across an organisation and improve value for money.
  - Project or programme Senior Responsible Owners (SROs) should be appropriately experienced and qualified, fully understand the governance and approvals process, the scope of their responsibility and commit sufficient time to guide projects and programmes through approvals and delivery.
  - Contracting authorities should adopt a portfolio approach to tracking major projects throughout their lifecycles. Central government's most important projects and programmes are tracked as part of the Government Major Projects Portfolio (GMPP).
  - Projects and programmes should have a proportionate early challenge review.
  - The delivery model assessment should take place early in the preparation and planning stage of a project or programme.
  - To complete a delivery model assessment, start by thinking about the outcomes you want to achieve, your strategic approach and a robust understanding of value before determining the appropriate commercial approaches for the delivery model.
  - Projects and programmes should undertake benchmarking of key project deliverables including cost, schedule, greenhouse gas emissions and agreed outcomes at each stage of business case development.
  - Should Cost Models (SCMs) should be produced as part of the planning and preparation stage to inform the delivery model assessment.
  - Effective, sustainable contracts should support project and programme outcomes, be designed to implement alignment with the selected delivery model, be consistent with the best practices and policies set out in this Playbook, drive continuous improvement, be structured to enable an exchange of data and contractualise the use of the UK BIM Framework.
  - Procurement processes should be of proportionate duration and effort to the size and complexity of the contract opportunity so as not to create barriers to entry for SMEs and VCSEs. The business case should justify the chosen procedure.
  - Standard frameworks and construction contracts with appropriate options selected should be used with standard boilerplate clauses (also known as model clauses).

- Publication
  - Conduct meaningful engagement with the market. Set a collaborative tone and provide clear escalation routes for suppliers.

- Risk should be allocated to, and managed by, those best able to bear and manage them (this includes the contracting authority). Contractual allocation should reflect the extent to which parties are responsible for risks and their management.

- Contracts should be designed to be profitable and offer a fair return for the market to be sustainable. It is good practice to test profitability under different circumstances and make use of the Should Cost Model in developing payment mechanisms.

- The payment mechanism and pricing approach including limits of liability should reflect the level of risk and uncertainty in the scope of requirement and will be subject to greater scrutiny.

- When a contract is publicly designated as onerous, it should prompt a root cause analysis and conversation with the supplier.

- Selection

  - The selection process is used, among other things, to determine whether bidders are able to comply with exclusion grounds and demonstrate suitability to carry out the contract.

  - The selection stage is an assessment of the bidders themselves, as opposed to the evaluation and award stage, which is an assessment of their bids.

  - The principle of prompt payment applies to all public procurement and all suppliers should pay their supply chain promptly.

  - The key purpose of assessing the economic and financial standing of bidders is to safeguard the delivery of public works and services. Observe the principles of public procurement: equal treatment, non-discrimination, proportionality and transparency.

- Evaluation and Award

  - Value-based procurement should be adopted at an organisational level and driven through a portfolio approach to projects and programmes.

  - Evaluation should focus on value rather than simply cost. Contracting authorities should evaluate bids for public works projects and programmes by determining the most economically advantageous tender (MEAT) based on their published award criteria.

  - Make use of the new social value framework and upcoming Project Scorecard to design fair, open and transparent evaluation criteria.

  - Use a robust definition of whole life value, Should Cost Models and benchmarking, to identify value drivers early in the project lifecycle and then ensure they are translated into evaluation criteria.

  - Resolution planning helps ensure continuity of critical projects and their orderly transfer to a new supplier in the event of supplier insolvency.

  - When reviewing suppliers' Service Continuity Plans for critical contracts, ensure they include a supplier insolvency continuity element. Make sure exit plans and exit information cover emergency exit arising from supplier insolvency.

  - Put in place your own contingency plans for critical contracts, with involvement from suppliers, keep them up to date and make sure they cover the risk of supplier insolvency.

  - Ongoing financial monitoring enables early identification of possible problems and the opportunity to test contingency plans before they are needed.

  - When considering the mitigation of risk against potential supplier insolvency, it is important to consider proportionality and the wider impact on suppliers and competitiveness.

- Contract implementation
    - Effective contract management is essential to drive value for money and deliver successful contractual outcomes.
    - Government's most important contracts should be managed by an expert or practitioner accredited contract manager as set out in the Contract Management Professional Standards framework.
    - Engage with the market and senior stakeholders to consider what type of relationship is most appropriate for your project and use this to inform your choice of procurement procedure and contractual model.
    - A strategic supplier relationship management approach can improve the delivery of objectives and increase mutual value beyond that originally contracted.

3.3.2 In Plain Sight

Following the Grenfell Tower disaster in 2017, the UK Institution of Civil Engineers commissioned a study regarding the risk of catastrophic failures in UK infrastructure assets (The UK Institution of Civil Engineers, 2018).

The report concluded that while the risk of catastrophic infrastructure failure is low, it is increasing. One of the key reasons was seen to be that 'the current industry structure and modern procurement methods can spawn numerous organisational interfaces throughout design, construction and whole-life stewardship which can interrupt asset knowledge and create data continuity risks' (The UK Institution of Civil Engineers, 2018, p. 6).

Despite this, the report makes no recommendations that address this directly other than to emphasise that someone needs to understand and be responsible for the overall risk posed by the system because 'every interface creates risk, hence the importance of the engineer's voice in aggregating and understanding the whole system risk' (The UK Institution of Civil Engineers, 2018, p. 33).

3.3.3 Victorian government guidance on procurement

Published guidance for public construction procurement in Victoria (Victorian Department of Treasury and Finance, 2018) published in 2018 provided the following principles for effective procurement:

- Ensure appropriate competition and contestability when undertaking Public Construction Procurement
- Employ the appropriate procurement delivery models and processes taking account of the complexity and value of the project and supplier market capability
- Appropriately plan and manage Public Construction Procurement to deliver procurement objectives
- Reduce unnecessary burden of Public Construction Procurement for all parties
- Encourage appropriate innovation and responsiveness in the supplier market
- Foster continuous improvement and building appropriate skills and capability in the conduct of Public Construction Procurement
- Conduct Public Construction Procurement in an open and transparent manner ensuring defensibility of processes
- Treat all tender participants fairly and equally
- Conduct Public Construction Procurement in an efficient and timely manner
- Undertake Public Construction Procurement in accordance with relevant legislation, policy, guidance and any mandatory requirements in the Directions

Projects that are designated high value and high risk in Victoria are required to follow the relevant Department of Treasury and Finance guidance (Victorian Department of Treasury and Finance, 2018). Guidance is published in three booklets addressing three investment lifecycle stages – business case, procurement and delivery. These are 'how to' guides with steps to follow but do not clearly set out the underlying principles so they are less useful for the purposes of our project.

3.3.4 Victorian Civil Construction industry

In 2008, the Civil Contractors Federation (CCF), the Municipal Association of Victoria and the Institute of Public Works Engineering Australia jointly published a Best Practice Guide for Tendering and Contract Management (Victorian Civil Construction Industry, 2008). The guide sets out some guiding principles and then applies them through the lifecycle of a civil construction project from project initiation, through contractor selection, tendering, evaluation, contract management, payments, dispute resolution and compliance. It targets specifically those involved in public infrastructure construction and maintenance.

In a similar vein, CCF and VicRoads undertook a study resulting in a 2009 report titled Achieving Civil Infrastructure Procurement Best Practice (CCF & VicRoads, 2009). The report considers six procurement options (construct only, design and construct, alliancing, managing contractor, early contractor involvement and public private partnerships). It sets out the pros and cons of each model against seven criteria:

1. Involvement of the contractor in the design process
2. Capacity of the client to make design changes
3. Ability to support a collaborative approach
4. Ability to support innovation
5. Organisational complexity of the project
6. Speed from inception to completion
7. Certainty of price

The actions arising from the report relate specifically to improvements in VicRoads contracting strategies and provides ten templates for use in that sector. Some of the underlying principles are relevant here including:

- Chose the right contracting strategy for the project. Complex, large, or uncertain projects in particular benefit from early contractor involvement and relational contracting models.
- Use standardised contracts where possible, rather than bespoke, different contracts on every project.
- Maintain a joint client / contractor project risk register and be transparent about risk allocation at all stages of the project in order to reduce disputes.
- Use prequalification systems to cover non-project specific performance criteria.
- Be aware of the impact of the size/scope of contract packages on potential bidders.

3.3.5 NSW guidance on procurement

In the wake of several major procurement failures (see Section 3.2), Infrastructure NSW has recently issued a Framework for Establishing Effective Project Procurement for Large, Complex Infrastructure Projects (Infrastructure NSW, 2021).

It states that best practice procurement must:

- ‘Be supported by early investigations to identify risks and an effective risk analysis and risk management plan to inform packaging and contracting discussions with industry, preferably undertaken in development;
- Engage industry and advisors in the pre-procurement phase to identify likely costs, risks and contingencies and to confirm the market has the appetite, capability and capacity to deliver the goods and services required;
- Foster and support strategic engagement to develop industry capability and capacity;
- Be based on a shared understanding of key drivers, expected outcomes and objectives between the client and contractors, enabling them to align their efforts and work together collaboratively in partnership;
- Provide an opportunity for industry to inform design to de-risk delivery;
- Utilise early works packages to mitigate site and utility risks where appropriate;
- Specify the required environmental and social standards through the process, i.e., at early market engagements, in the key documentation (the terms of reference, evaluation criteria etc.);
- Size works into packages to develop capability, use available industry capacity and to encourage a competitive bidding market to increase value for money;

- Include in the budget a risk allowance, using a probabilistic assessment of known risks included in the risk register, and a deterministic contingency allowance, to cover unknown or strategic risks;
- Allocate risk to the party best able to manage it. This must be based on an understanding of the risks best managed internally and the risks the market can better manage externally;
- Utilise open book, target cost and incentivised cost approaches for risks that cannot be efficiently priced and/or transferred to the private sector;
- Adopt and comply with a clear and transparent procurement process (including approvals and assurance);
- Recognise shared reputational impacts, benefits, risks and rewards.' (Infrastructure NSW, 2021, p. 5)

The framework aims to achieve these by application of seven key default practices:

- Engage with industry (including potential suppliers) early;
- Seek contractor input early in the design process in order to generate the best engineering solution;
- Facilitate early works packages to de-risk delivery;
- Size project packages to attract competition;
- Move towards more collaborative contracting approaches by Increasing use of open book/target costs and standard contracts;
- Include sufficient risk allowances in cost estimates;
- Undertake tender processes that are efficient and cost-effective.

It adopts an 'if not, why not' approach i.e., these practices must be applied or a justification provided as to why they are not being followed in any particular case.

These principles were emphasised in a Premier's Memorandum M2021-10 Procurement for Large, Complex Infrastructure Projects issued in June 2021 (NSW Government Premier & Cabinet, 2021) which sets out required practices in three areas:

- De-Risking Pre-Construction
    - Use early contractor engagement to identify, mitigate and nominate risks that cannot readily be included in lump sums
    - Designate and undertake early works
    - Expedite project by using pre-qualified panel members, using an open-book payment basis if necessary.
- Procurement approach
    - Size contract packages to facilitate competition.
    - Use open book and/or target costing for high-risk project elements
    - Ensure that risk allocation between client and head contractors is passed down to subcontractors where practicable.
    - Maintain consistency and simplicity of contracts across projects
    - Include proposed contracting terms and risk allocation in early engagement discussions
    - Recognise international experience but encourage local partnerships
    - Structure contracts to reward cost saving and innovation
- Reducing costs and improving timeframes
    - Use realistic tender timetables – don't rush
    - Ensure timely completion of tenders and contract award
    - Consider deferring projects where tender results do not yield acceptable outcomes
    - Undertake a holistic review of tender requirements and hence costs to ensure requirements are not excessive
    - Optimise design development to avoid duplication without eroding the intended allocation of risk
    - Use prequalification processes to avoid contractors having to submit systems and plans on multiple occasions.
    - Increase the State's role in stakeholder management and project communications.

The focus on contracting arrangements and upfront effort in these documents emphasises the extent to which these areas are important in managing procurement risk. Many of the details are equally appliable in the private sector context.

3.3.6 Austroads and the Australian Procurement and Construction Council

Austroads and the Australian Procurement and Construction Council (both government agencies) jointly published a procurement guide in 2014 (Austroads, 2014). The guide states that it is for use by government agencies in the civil and non-residential building sectors and was prepared with input from industry and all relevant government agencies. The underlying principle is that a 'raft of positive outcomes ... can be achieved by fostering positive relationships with industry and building provision for teamwork into contracts including improved efficiency, decreased disputes and practical, progressive learnings that can be applied to future projects.'

The guide provides a general description of commonly used procurement delivery models including a summary of the key characteristics of each one and the advantages and disadvantages of each. Models described are:

- Construct only
- Design and construct (including variants)
- Managing contractor
- Construction management
- Direct managed
- Early contractor involvement
- Alliancing
- Public private partnerships

Of most relevance to this project are the principles that the guide gives regarding successful contracting as reproduced below (Table 13).

Table 13. Contracting principles for construction and professional services (reproduced from Austroads (2014))

Subject	Principle
Procurement method	▪ Use standard or government-owned forms of contract where possible. ▪ Select the form of contract and tendering process to suit the delivery model for the project.
Innovation	▪ Include provision in contracts to encourage innovation.
Collaboration	▪ Where collaborative principles are used, include obligations for all project parties in the contract.
Risk allocation	▪ Allocate risk to the party best able to manage the risk. ▪ Clearly define roles and responsibilities of the parties and identify the responsibility for management of each key risk.
Limitation of liability	▪ Where liability capping is considered: – it is to be on the basis of rigorous risk assessment in accordance with jurisdictional policies – regard is to be had to the level of insurances to be provided under the contract by the principal and/or contractor. ▪ Consider limiting indirect or consequential losses of both parties where these can be appropriately defined.
Warranties	▪ Limit warranties to the work and services to be provided by the contractor, including subcontractors, consultants and suppliers. ▪ Fitness-for-purpose warranties are ascertainable from the contract.
Indemnities	▪ Do not require the contractor to indemnify the principal for the principal's (including its employees and agents) negligent actions.

Insurances	▪ Apply a risk-based approach to determining insurance types and levels that are appropriate to the contract. ▪ Reference full details of insurance which benefits other parties in the contract and/ or make this information available to the contractor.
Intellectual property	▪ The contractor retains ownership of pre-existing intellectual property, and an irrevocable licence to use this property is provided to the principal for the purposes of the project. ▪ In circumstances where ownership of intellectual property created during the term of a contract is owned by the principal, contractors are able to use it under licence.
Confidentiality	▪ Confidentiality provisions are to be defined in the contract and appropriate to the needs of the project.
Key personnel	▪ Key personnel nominated for the project at tender time are to be supplied. ▪ Contract personnel are to have skills and experience appropriate to their roles.
Subcontracting	▪ Subcontracting of the whole-of-the-works is not permitted.
Cost adjustment	▪ The inclusion of cost adjustment provisions, where relevant to the contract and its duration, is to be considered.
Dispute resolution	▪ Adopt a collaborative approach. ▪ Include alternative dispute resolution procedures in the contract.
Electronic notices	▪ Use electronic documentation and notices, where practicable.
Additional principles applicable to construction	
Security	▪ Subject to jurisdictional requirements, security in the form of unconditional undertakings from various security providers (acceptable to the principal) is to be permitted. ▪ Unless specifically required to manage identified risks, principals should consider including a provision in contracts for the release of part of the security after practical completion (or equivalent).
Overheads and profit	▪ Define in the contract what is covered by payments for overheads and profit, where such payments apply.
Site conditions	▪ Detail in the contract which party is responsible for which site conditions.
Time management	▪ Include provisions for the management of extensions of time in the contract. ▪ Unless otherwise specified in the contract, the contractor owns the float.
Defects liability	▪ Set the defects liability appropriate to the delivery model and the scope, complexity and value of the contracted works.
Subcontractor conditions	▪ Subcontract conditions are to align with the contracting principles included in the head contract.
Additional principles applicable to professional services principles applicable	
Novation	▪ Where novation is included in the tender documents, the successful tenderer will comply with the required novation.

3.3.7 Australian Standards

There are two Australian Standards that have been identified that are within the project scope, but neither are particularly useful for large, complex projects. AS 4120 – 1994 Code of tendering sets out the ethics and obligations of the Principle and Tenderers in tendering in the construction industry. It is very basic and does not contribute usefully to this project. AS 4121 – 1994 and AS 4122 – 2010 provide similar information for selection of consultants (by direct invitation and tender respectively).

3.3.8 World Bank

The recently published policy research working paper from the World Bank (World Bank Group, 2021) points out that OECD members spend between 12% and 45% of government expenditure on procurement covering both spending on major infrastructure and recurrent administrative expenses. It focuses on two overarching policy objectives in reviewing current practices internationally. They are:

- Improving value for money and
- Promoting fair and open access to public contracts.

Looking at studies of public procurement interventions globally they draw some conclusions that are relevant to the private sector context including:

Centralised and collaborative procurement

A study of pharmaceuticals purchasing in Italy showed a 60% saving moving from local purchasing to centralising and collaborative purchasing. Similarly, moves to a framework agreement rather than use of local purchasing contracts led to 34-78% costs saving also in Italy but in a different market. The main effect was the result of standardised products and increased market power to negotiate on price. This general finding may very well be valid in a future fuels context given the number of small projects underway. It is likely that centralised and collaborative purchasing may result in lower costs in this context too.

Civil society supervision

A large-scale study of procurement in development projects in Peru showed a saving of 51% achieved by involving end-users (in this case local communities) with procurement. In this context, it not only reduces corruption but ensures final outcomes are more fit for purpose. The equivalent in the context of future fuels projects is to involve end users in the procurement process.

Rule bound or discretionary decision making

Studies on formal rule-bound tender evaluation versus negotiation with a single or limited group of suppliers show mixed results. The limited research in this area in a development project context shows that more complex projects appear to achieve better outcomes based on negotiation.

Performance pay and incentives

The report notes that performance pay and financial incentives have recently become popular in public procurement to align the behaviour of individuals with organisational objectives. There is no evidence regarding the effectiveness (or otherwise) of these measures.

Professionalisation and capacity development

The report notes that one of the key factors impacting effective procurement reform in the development sector is lack of skilled resources.

Dispute resolution

An annual report regarding construction disputes is published each year by the consulting firm Arcadis. The 2021 report (Arcadis, 2021) gives insights into issues currently causing disputes on major construction projects and so how they might be prevented.

The overarching recommendation of the report is the need for effective preparation. The study shows that the right preparation reduces the risk of a disagreement becoming a full-blown legal dispute. Effective preparation also sets up the best possible processes to be followed in the event that disputes do arise.

The report notes an increase in construction activity globally post-Covid, particularly larger and more complex projects with more stakeholders and rapidly changing technologies. Against this background, the average value of disputes increased significantly. 'Proper administration of the contract was a theme across the globe for the successful and early resolution of disputes' (Arcadis, 2021, p. 4) which were mostly settled through party-to-party negotiation.

Overall, the most effective claims avoidance techniques identified for 2021 are:

- A good risk management plan
- Conducting contract and specification reviews
- Third party schedule reviews
- Constructability reviews

Based on multi years of reviews of dispute resolution, measures at each project stage that reduce/minimise the impact of disputes are:

- Preparing the project team. Ensure that the project team understands their obligations under the contract and how changes are to be managed.
- Have a well thought out risk management plan
- Chose a contract type that is best suited for the type of project, including provisions for dispute resolution.
- Make sure key project documents are accurate and complete. Errors and omissions in design basis documentation is a key cause of disputes.
- Manage the schedule carefully as delay, acceleration and disruption are key causes of dispute.
- Document everything. Lack of documentation is a key cause of dispute.

If litigation is necessary to resolve disputes, keep things objective. External experts can provide perspectives on the strengths and weaknesses of your position.

3.3.9 Key features of published procurement guidance

The published procurement guidance documents reviewed above have many common features. They all aim to support successful project outcomes even if they do not always present the material in terms of procurement risks to be managed or avoided.

A summary of common principles and practices (where given in the guidance) is shown in Table 14.

Table 14. Principles for successful procurement and supporting practices

Principles for successful procurement	Supporting practice
Appropriate, clear and efficient specifications are a critical factor in the overall timely and cost-effective delivery of projects	
Good approvals processes should be consistent, transparent and streamlined to enable effective decision-making across an organisation and improve value for money	Set up systems. Don't rush tendering or bid evaluation.
Ensure procurement includes a selection stage that assesses the bidders themselves and their overall suitability to do the work (rather than evaluation of their bid for a specific piece of work).	Use prequalification systems to cover non-project specific performance criteria.
Chose the right contracting strategy for the project. Complex, large, or uncertain projects in particular benefit from early contractor involvement and relational contracting models.	

Be aware of the impact of the size/scope of contract packages on potential bidders.	Size works into packages to develop capability, use available industry capacity and to encourage a competitive bidding market to increase value for money
Effective procurement is based on a shared understanding of key drivers, expected outcomes and objectives between the client and contractors, enabling them to align their efforts and work together collaboratively in partnership	Engage with contractors and suppliers early to: 1) make best use of their experience to identify likely costs, risks and contingencies 2) to confirm the market has the appetite, capability and capacity to deliver the goods and services required. 3) facilitate collaboration.
Risk should be allocated to, and managed by, those best able to bear and manage them.	Contractual allocation should reflect the extent to which parties are responsible for risks and their management. Ensure that risk allocation between client and head contractors is passed down to subcontractors where practicable. Establish and maintain a joint client / contractor project risk register and be transparent about risk allocation at all stages of the project in order to reduce disputes.

3.4 Other sources of information

While conducting the literature review and speaking to stakeholders, we have come across many excellent sources of information related to management of projects, project risk governance and supply chain management. Specific references are made in the text to individual publications, but Table 15 summarises some key information sources that may be more broadly useful as the project progresses and for industry partners.

Table 15. Useful sources of information on project management topics

Title	Link	Description
The Association for the Advancement of Cost Engineering International (AACEi)	https://web.aacei.org/	AAECi seeks to apply 'scientific principles and techniques to problems of estimation; cost control; business planning and management science; profitability analysis; project management; and planning and scheduling'. They have a published Body of Knowledge
Project Management Institute (PMI)	https://pmi.org/	PMI is a US-based member organisation. They publish a range of standards related to project management including the well-known Project Management Body of Knowledge (PMBOK).
Independent Project Analysis (IPA) / Ed Merrow	https://www.ipaglobal.com/	IPA is a consulting firm specialising in data analytics to improve capital competitiveness of mega projects. The Founder and President is Edward Merrow who has published several useful books on megaproject management and lessons from megaproject failures.
Engineers Australia Risk Engineering Society (RES)	https://www.engineersaustralia.org.au/Communities-And-Groups/Technical-Societies/Risk-Engineering-Society	EA's RES has published several technical guidelines including one on managing schedule and cost contingency reserves.
Engineers Australia Risk Engineering Body of Knowledge (REBOK)	https://rebok.engineersaustralia.org.au/	RES also runs a Wiki-based BOK on engineering and risk topics.
Association for Project Management (APM)	https://www.apm.org.uk/	APM is a UK-headquartered member organisation that publishes books on project management including their well-known APM Body of Knowledge
Chartered Institute of Building (CIOB) Academy	https://www.ciobacademy.org/publications/	The CIOB is a member organisation for those in the field of construction management. It has a separate Academy arm which runs courses and sells publications regarding construction management topics.
Society for Construction Law Australia (SoCLA)	https://www.scl.org.au/	SoCLA publishes guidance material for use of members on construction law topics such as contracting.
International Association of Oil & Gas Producers (IOGP)	https://www.iogp.org/international-standards/ https://www.iogp-jip33.org/ https://committee.iso.org/home/tc67	This project aims to produce more common standards for the oil and gas sector. Working together with ISO, IOGP members work together to develop and publish draft standards which are then made available to ISO Technical Committee 67.

Standardization Project		There is an Australian mirror committee sponsored by NERA and linked to Standards Australia ME-092.
The Dispute Resolution Board Foundation (DRBF)	https://www.drb.org/publications	The Dispute Resolution Board Foundation (DRBF), a member-based, non-profit organization to promote the avoidance and resolution of disputes worldwide using the Dispute Board (DB) method.

4 Conclusions

Referring back to the research questions in the introduction the results of the work to date are summarised below.

- Why have past significant procurement failures in the gas industry and elsewhere occurred? What can be learned from them?

A preliminary taxonomy of procurement risks has been constructed based on a literature review and information on past procurement failures that is in the public domain. A wide range of risks have been identified with the two most commonly occurring in the failure cases identified as 1) problems with supply chain configuration (e.g., selecting a supplier who is not suitable) and 2) QA/QC issues (e.g., tests not conducted or not reflecting service conditions). As expected, there is little data on gas sector procurement failures that is readily available to draw on. Rather, this data needs to be gleaned from the experience of industry professionals interviewed for the next stage of the work.

- What are the risks associated with the procurement process in the gas industry and what risk governance practices can be used to prevent the recurrence of procurement failures in the context of future fuels?

Data is being collected on this in the second phase of the project (not reported on as yet).

- What does a robust procurement risk governance framework look like in a future fuels environment?

This will be developed in later stages of the project.

Most of the work done to date provides input into later stages of the project but procurement failures cases may be directly useful to industry in their current form. Experienced professionals learn best by considering cases and the report provides nineteen examples of procurement failures that an provide the basis for discussion to reflect on current procurement practices and the potential for the same weaknesses to be present in any specific set of procurement practices.

5 Implications and recommendations for industry

Implications and recommendations for industry will be developed in later stages of the project.

6 Next steps and future works

Fieldwork with industry stakeholders across the entire supply chain for procurement of both good and services in a project environment and in operations is currently underway. That information combined with the findings of this report will be used to continue the project. The next report is due in June 2022.

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