4 Project Risk Management

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Failure to deliver projects can significantly harm the engineering and construction firms that build them, as well as the clients who engage these firms. For example, in 1989, Davy Corporation, a British engineering and construction firm, secured a large fixed-price project to convert an exploration rig into a oil production platform. The terms were 25 percent down and 75 percent on first production of oil. Severe cost and schedule overruns resulted in serious losses for Davy. As a result, in 1991, Davy Corporation was bought by Trafalgar House, a British conglomerate, at a much diminished share price. Later in 1991, the oil production platform finally went into operation, about two years behind schedule and in a very different business environment. The client was not able to buy back the rig per the original agreement. Trafalgar House was forced to write down the book value of the rig and charter the rig to the client for about 50 percent of normal rates to generate some revenue. This project, plus losses from other parts of their operations, eventually resulted in Trafalgar House itself being purchased in 1996. So not only was poor management of project risks disastrous for Davy, but the client and Trafalgar House incurred large losses owing to the delays.

By definition, projects are temporary undertakings having start and finish dates (a schedule). In addition, projects must meet certain requirements that satisfy the objectives for which the project is being undertaken (project scope) while meeting a budget for the project.

Because the resources available for completing a project (i.e., time, money, and human resources) are limited, the often competing demands of project schedule, scope, and budget must be balanced to best meet the project objectives. Furthermore, a project must also satisfy the objectives of a number of different project stakeholders, including the project owner, government, local community, equipment vendors, and construction contractors.

A formal risk management program provides a sound basis for decision making on projects to balance all these competing demands. Although management of risks on projects shares a lot of the same fundamentals and elements as the management of risks for the normal operation of enterprises, the different context requires that the focus of risk management on projects be different.

One of the key risk mitigation strategies on projects is to undertake projects in phases, where incremental financial commitments are justified by increasing levels of project definition and development actually achieved. Different industries use different project life cycles with different terminology used to describe the various project phases. However, the underlying concept of a project being completed in phases is universal. Because of the author's experience in mining and metals, this chapter will be based on the typical project life cycle used in those industries. In this chapter, we will illustrate project risk management using the following project life cycle scheme:

1. Conceptual study
2. Prefeasibility study
3. Feasibility study
4. Project execution

This chapter focuses on managing risks during the execution of engineering and construction projects. Some of the principles described in this chapter would apply to other sorts of projects, such as large software engineering projects. This chapter describes the following:

- Types of risk on projects
- Risk management activities over the project life cycle
- Managing the risk of being on time and on budget

Background

Everyone has responsibility for risk management on a project, but common practice is to appoint a single project risk manager to coordinate risk management activities and to provide specialist expertise.

One of the first tasks of the project risk manager is to develop the following four key risk management documents:

- Project risk management policy
- Project risk management plan (part of the overall project plan)
- Risk management procedures
- Risk registers

These should be consistent with the analogous enterprise risk management documents. However, since the context of a project is very different from the context of the normal operations of an enterprise, the enterprise risk management documents have to be modified to suit project requirements to produce project-specific documents.

The risk management policy is usually the same as the corporate risk management policy.

Two project plans are prepared toward the end of each project phase. One plan documents the plan for completing the subsequent project phase, and the other documents the plan for executing the project. The project risk management plans are subsidiary plans of each of these project plans.

One risk management plan describes how the risk management process described in Chapter 1 will be implemented during that phase, whereas the other describes how the risk management process will be implemented during project execution. For example, the project risk management plan for the conceptual study phase describes how risks will be identified, analyzed, and prioritized during the conceptual study and can give general guidance for how risks should be mitigated. For example, one firm may emphasize transferring risks to other parties when practical, whereas another may emphasize mitigating them itself.

In a project, conditions change quickly. The risk register is where the risks identified during risk assessment are recorded. As a result, the risk register normally is updated monthly. During the update, the assessments of previously identified risks are reviewed, new risks identified and assessed, the status and effectiveness of existing risk treatment plans assessed, and new risk treatment plans developed as required for both existing and new risks. The result is an updated risk register.

The ongoing operations of an enterprise are relatively standard and stable. As a result, the tools and techniques used for assessing risks tend to be limited in number, standardized, and used across the entire organization. However, projects, by their very nature, are dynamic, and different tools and techniques are used to assess risks during different project phases to suit the specific requirements of a given project phase.

Enterprises define key performance indicators (KPIs) for assessing the health of their organizations. These KPIs are selected to suit ongoing operations of the enterprise. Projects may require different KPIs to assess project health. The main project-specific KPIs are capital cost and project schedule. In addition, the rating scales that many enterprises use for assessing the magnitude of the consequences of a given risk on a KPI must be modified to suit project-specific requirements. Depending on project size, a risk that is insignificant to the enterprise as a whole could be catastrophic to the project.

Types of Risks in Projects

Risks on projects can be roughly divided into project risks and technical risks.

- **Project risks** are those that occur during the execution or building of the project. For example, suppose a piece of equipment such as a specialized filter needed for a smelter can only be purchased from a limited number of suppliers. If there is high demand for this product and none of the suppliers can supply it on time, the timelines for completing the project will be threatened. Generally groups such as construction, purchasing, finance, and human resources are responsible for managing project risks.
- **Technical risks** are risks that occur during the operation of a project after it is completed. For example, a tank is designed and built in such a way as to create a risk of overflowing and spilling into a river during the operation of the plant. This type of risk should be identified during the design of the project and mitigated by modifying the design.

Sources of Project Risks

Project risks arise from such things as the following:

- **Project location:** This includes geopolitical conditions, legal/regulatory environment, and manmade or natural catastrophes. For example, the risks posed by severe weather events such as floods, hurricanes, tornadoes, or extreme temperature during project execution and subsequent operation of the facilities associated with the project must be addressed.

- **Economic, industry, and market environment:** This includes demographic trends, inflationary environment, business cycle, changes to the business structure, changes in the price of inputs (both for completion of the project and for subsequent ongoing operations), and changes in interest rates or foreign exchange rates. For example, some project proponents purposely proceed with projects when the overall business cycle is in a trough. Although a project proponent must have the necessary financial resources, this will reduce the likelihood of cost overruns, for the equipment, material, and human resources required to execute the project can likely be procured at lower prices. Conversely, severe cost overruns can result when projects are executed at a peak in the business cycle.
- **Project size, complexity, and uniqueness:** Large projects tend to be more complex than smaller projects, with increased numbers of communication channels and increased levels of project governance. This tends to make large projects riskier than small projects.
- **Financial strength of the project proponent:** It may be prudent for the project proponent to find a partner with whom to share financial risk. However, this will introduce new risks related to project governance, for there will now be two different entities involved in the project.
- **Technology:** Projects using leading-edge, state-of-the-art technology will require extensive bench scale, pilot scale, and demonstration scale testing to prove out the technology and develop the design criteria required to complete detailed design for a commercial facility. Projects using mature, well-established technology will not require this extensive testing.
- **Logistics:** The transport of equipment, material, and people to and from the project site can be a major undertaking. Planning for this transport must take into account the maximum load dimensions and load weights imposed by the transport route. For example, a plant located on the coast could take advantage of the cost savings resulting from pre-assembled units or modules and barge transport to the site. On the other hand, a plant located inland will be restricted in terms of load size by the dimensional and load limits of the access road or rail line. As a result, extensive pre-assembly would not be an option.
- **Communication:** Communication becomes more complicated as project size increases and on remote project sites. Satellite communication or the installation of fiber optic cables may be required for the communication system to provide the bandwidth required by the project.
- **Design:** It may be advantageous to use low-cost global execution centers to design the facilities. However, coordination with the global execution centers is more complicated than if a local execution center was used.
- **Procurement:** Procurement risks relate primarily to the availability and quality of equipment vendors and construction contractors. There is a risk that costs could be higher if vendor or contractor availability is low owing to lack of competition.
- **Construction:** Construction risks can be due to extreme weather, the layout of the overall plant site, or the skill and number of construction craft workers available. For example, qualified local construction craft labor may be in short supply, and an extensive

training program may be required if labor from outside the immediate plant area cannot be brought in.

- **Commissioning:** The simplicity of equipment and system commissioning will vary from project to project. This will affect commissioning duration and commissioning labor requirements.
- **Integration with existing operations:** If the project is an expansion to existing facilities, then integration of project execution and operation of the new facilities with the existing facilities must be addressed. For example, there is the risk that construction of the new facilities could affect operation of the existing facilities or that operation of the existing facilities could affect construction of the new facilities.
- **Human resources:** Human resources are frequently a major source of risks on projects. Project cost and schedule can be affected depending on how the project team works together as a team.
- **Sustainability:** Sustainability is becoming more of an issue on projects. Sustainability issues include community and heritage values, disease and health risks, potential releases of hazardous materials, high sound levels, the effects of an industrial or environmental disaster, and conservation and endangered species. (See the chapter on environmental risks for more.)

Sources of Technical Risks

Technical risks are normally managed separately from general project risks, being primarily associated with the design of the facilities. Assessment of technical risks is an integral part of the design of the facilities associated with the project. Early in the project life cycle, technical risk management is used to guide the design of the facilities. Later in the project life cycle, technical risk management is used to verify the design of the facilities.

Treatment plans must be developed for all of the intolerable technical risks. In addition, as a second priority, treatment plans are developed for technical risks falling in the tolerable category. Treatment plans for risks in this category are defined based on cost/benefit analysis, where the risk severity is reduced to a level as low as reasonably practical (ALARP). In most cases, the treatment plans are related to the design of the facilities, whereas in some cases, the treatment plans are related to standard operating or maintenance procedures.

Sources of technical risks include the following:

- Fires or explosions
- Chemicals
- Pressure extremes
- Temperature extremes
- Mechanical conditions
- Radiation
- Electrical conditions
- Physiological conditions
- Human factors

- Ergonomic factors
- Control systems
- Vibration
- Motion
- Operating mode
- Miscellaneous conditions

Managing Risks during the Project Life Cycle

The phased approach to project risk management is used when projects are executed in phases, with formal reviews at the end of each phase. The initial phases focus on conceptual and preliminary design of the product or service the project is to provide, whereas the later phases focus on detailed design and actual execution of the project.

A progressive and phased increase in investment in a project, in line with progressively decreasing risk and increasing clarification and certainty over time, is the key to the project life cycle. Each incremental investment is made when the level of risk and certainty justifies it, rather than committing large sums to an uncertain investment at the outset. In one project, a large mining company was interested in extracting magnesium from asbestos tailings. During the feasibility study, a pilot plant was built and tested and appeared to work. The project proceeded to construction and operations. The extraction plant failed very soon thereafter, at great cost to the mining company. A key was not identified: that impurities would build up inside the equipment during continuous operations, impeding production. Had this risk been identified during the feasibility study, the project might have been canceled or redesigned at that point.

Conceptual Study

The purpose of the conceptual study is to determine whether there is a viable business case for the project based on the product to be produced, the markets for the product to be produced, proposed plant capacity, and proposed plant location. In addition, a workable plan and associated schedule and cost are developed for completing the next phase of the project, the prefeasibility study. At the end of the conceptual study, a decision is made to commit funds for the prefeasibility study and on the alternatives that will be studied further during the prefeasibility study.

For project risks (those risks primarily associated with completion of a project phase or final project execution), the effort focuses on assessing the major risk issues, identifying any fatal flaws, and identifying any special treatment actions and determining if they are practical during the execution and operation phases. Normally brainstorming is used to identify risks, and qualitative likelihood of occurrence and consequence magnitude scales are used to assess risk severity. The major deliverable is a conceptual level project risk register. An example of a typical project risk that would be identified during this phase of a project would be competition from other similar projects with similar finish dates that would increase market supply, reduce product prices, and reduce revenue.

Allowances are made in the capital cost estimate for contingency (known unknowns; the amount of money needed above the estimate to reduce the risk of cost overruns to a level acceptable to the organization) and in the schedule for additional float (the amount of time that activities can be delayed from their earliest start dates without delaying the project finish date).

For technical risks (those risks related to the effect on people, the environment, and physical assets during construction, commissioning, operation, and maintenance), the effort is concentrated on understanding the project, the process, and the materials involved and on identifying major hazardous facilities (facilities posing intolerable risk to people, the environment or physical assets). This way, issues can be assessed in more detail during later phases. Brainstorming is normally used to identify technical risks using conceptual site layout drawings, process block diagrams, and Material Safety Data Sheets (MSDSs) as inputs. The principal deliverable is a conceptual level technical risk register and a list identifying major hazardous facilities that focuses on the most critical technical risks. An example of a major technical risk that could be identified during this phase of the project would be the risk from using a toxic raw material in the production process.

During the conceptual study, the treatment plans and actions can involve major changes to the plant design, site plot plan, or general arrangement of the facilities. These major changes can, in turn, significantly affect the capital cost of the new facilities and the project schedule.

Prefeasibility Study

The purpose of the prefeasibility study is to select the best alternative for producing the product in the quantities defined at the location selected and to more rigorously test the project's viability. Moreover, a workable plan and associated schedule and cost are developed for the next project phase, the feasibility study. At the end of the prefeasibility study, an alternative is selected and a decision made to commit funds for the feasibility study.

Project risks are assessed and risk treatments defined for each alternative studied for decision making. Then the risk register is finalized for the preferred alternative. Normally, a checklist is used to identify risks and the major deliverable is a preliminary project risk register. Monte Carlo simulations of the capital cost estimate and the project schedule are used to establish the contingency reserve to be included in the capital cost estimate and the additional float to be included in the project schedule. The Monte Carlo simulations incorporate the effect of risks from the risk register that would affect project cost and schedule, plus the effect of the imprecision associated in estimating capital cost and schedule. A typical project risk that would be identified during this phase of the project would be the risk from selecting a process requiring extensive bench scale and pilot scale testing before the plant could be designed and constructed.

For technical risks, significant and major risks and their causes and consequences are identified, and risk treatment actions for all of the intolerable risks and some of the tolerable risks are incorporated into the plant design. Normally, a checklist of generic technical risks is used to identify the technical risks using preliminary site plot plans, preliminary process flow diagrams and preliminary general arrangement drawings as inputs. The principal deliverables are a preliminary technical risk register for the preferred alternative and for each of the alternatives evaluated.

Treatment plans and actions defined during the prefeasibility study normally involve more moderate changes to the general arrangement of the facilities and provide guidance for the design of the facility process control system. An example of a technical risk that would be identified during this phase of a project would be the risk of a release of a toxic material from the plant resulting from the loss of control over plant operations. The mitigating action could be to add interlocks to the plant control system to shut down the plant and prevent the release of toxic material.

Feasibility Study

The purpose of the feasibility study is to more fully define the selected alternative and develop a detailed plan for executing the project during the final phase of the project. Particular emphasis is placed on aligning the project schedule, scope, and capital cost estimate to the project plan and establishing the performance measurement baselines against which performance will be measured during project execution. At the end of the feasibility study, a decision is made to commit the often large sums of money to actually build the facilities that will be the end product of the project.

In terms of project risks, a full risk assessment of the selected alternative is conducted and finalized. In addition, risk treatment plans are defined for all of the intolerable risks and the most serious of the tolerable risks. The key deliverable is an updated project risk register. An example of a project risk that would be identified during this phase of a project would be the risk of late equipment deliveries caused by a lack of suitably qualified equipment vendors and qualified vendors already having full order books.

In addition, any specific detailed risk assessments that may be required to understand key project uncertainties are completed. Finally, Monte Carlo simulations of the capital cost estimate and project schedule for the selected alternative are completed to establish the contingency reserve to be included in the capital cost estimate and the additional float to be included in the project schedule.

For technical risks, a more detailed qualitative assessment of risks and their causes and consequences is completed and risk treatment actions finalized for all intolerable risks and the most serious of the tolerable risks. Contrary to the technical risk assessments done during the conceptual study and prefeasibility study, the technical risk assessment done during the feasibility study is used to verify plant design, not guide plant design. In addition, special quantitative studies may be started for intolerable risks requiring further study. A typical technical risk identified during this phase of a project would be the risk of producing poor-quality product as the result of not having included adequate analysis equipment in the plant design.

The hazard and operability (HAZOP) study technique is used for identifying risks in the design of process plants. It involves a detailed examination of the piping and instrumentation diagrams (P&IDs) and the control system functional description. The P&IDs show all of the process lines in the facility and the associated control hardware, such as switches, measurement elements, and control valves, and the functional description describes all of the functions to be programmed into the control system.

The HAZOP study technique is a structured brainstorming technique that uses guidewords to identify deviations from the design intent. The technique was originally developed by Imperial Chemicals, Inc. (ICI), for continuous flow process plants but has been extended to cover batch-type operations having discrete, discontinuous steps.

In a HAZOP study, each guideword (i.e., no, more, less, as well as, part of, reverse, other than, early, late, before, after) is applied to each parameter (e.g., flow, temperature, or voltage) associated with a process line on a P&ID to identify potential deviations, such as high flow, high pressure, or high temperature. For example, high pressure could result in a process vessel because of a high temperature caused by inadequate cooling water flow. After a meaningful deviation from the design intent has been identified, the causes and consequences of the deviation are noted. In addition, any controls in the existing design that will prevent, detect, or react to the deviation are identified. In the example discussed above, perhaps the design already incorporates low exit cooling water flow alarms and interlocks and high exit cooling water temperature alarms and interlocks. Then taking into account the effect of the existing controls, the likelihood and consequences are rated. For intolerable risks above the tolerable threshold, additional controls are identified that must be incorporated into the design. Again in the example discussed above, perhaps a pressure relief device should be incorporated in the process vessel to prevent a dangerous buildup of pressure.

The principal deliverable is an updated technical risk register with a list of proposed treatment actions. Each of these actions must be formally approved by the client before the changes can be incorporated in the facility design.

In addition, specialized techniques such as fire/explosion/gas dispersion modeling, fault tree analysis, event tree analysis, bow-tie analysis, human reliability analysis, machinery safety studies, layer of protection analysis (LOPA), safety integrity level (SIL) determination, or control system hazard and operability (CHAZOP) analysis are used to analyze the most serious, intolerable technical risks.

During the feasibility study, the treatment plans and actions involve mainly minor changes to the control system. In a few instances, minor revisions to the layout of the facilities are required.

Project Execution

During this phase, the capital investment is made and all the goods and services required to construct the plant procured. Equipment is purchased from vendors, construction contractors are engaged to build facilities and install equipment, and the plant is commissioned and started up.

The project risks identified during earlier phases are monitored on an ongoing basis to assess the effectiveness of the risk treatments. In addition, earlier assessments of previously identified risks are updated based on new information, and new risks are identified. An example of a project risk that might be identified during this phase of a project would be the risk resulting from inadequate power being available for construction. Finally, periodic Monte Carlo simulation of the project cost and schedule are used for estimates at completion in terms of cost and project duration.

Similarly, the effort on technical risks focuses on ensuring that all previous treatment actions are incorporated into the design and on identifying any new risks that must be treated. Also, all special quantitative studies are completed. The treatment plans and actions almost exclusively relate to changes to the control system. Only in a few instances are changes made to the facility layout.

Managing the Risk of Being Late and Exceeding Budget

Two of the key activities during each of the four project phases are the development of a capital cost estimate and a project schedule. Initially, they are developed as a single estimate of the estimated cost and a single date estimating the project end date, without any estimate of the possible variation (higher or lower) around these estimates that may occur in the final project. How well these single point estimates actually represent the actual costs and project duration depends on the level of project definition and the uncertainty associated with the estimates. During the conceptual study, allowances based on percentages are added to the base capital cost estimate and project schedule to allow for uncertainties. During the prefeasibility study, feasibility study, and project execution, Monte Carlo simulation is used to establish the contingency reserve to be included in the capital cost estimate and the additional float to be included in the project schedule.

Technical risk management activities and project risk management activities have different effects on the capital cost estimate. The technical risk management activities completed during any given project phase allow the facility design to be completed. This mainly affects the direct costs associated with the final, permanent end product of the project, such as the purchase and installation of equipment. The project risk management activities completed during any given project phase primarily affect the project indirect costs incurred to complete the project that are only indirectly associated with the project's end product (e.g., temporary construction facilities, spare parts, and construction management).

Although the project schedule can be affected by technical and project risk management activities, the project risk management activities have a larger effect on the schedule than the technical risk management activities.

To determine the possible variation from the single estimates for budget and timing, the first step is to estimate ranges for the unit price and quantities for the major cost estimate elements and duration of the major project schedule elements and then to estimate the correlations among the major elements.

After these initial steps have been completed, a Monte Carlo simulation model of the schedule is developed. In the simulation, the project is "completed" numerous times. The result of the simulation is a distribution of project schedule outcomes in terms of project

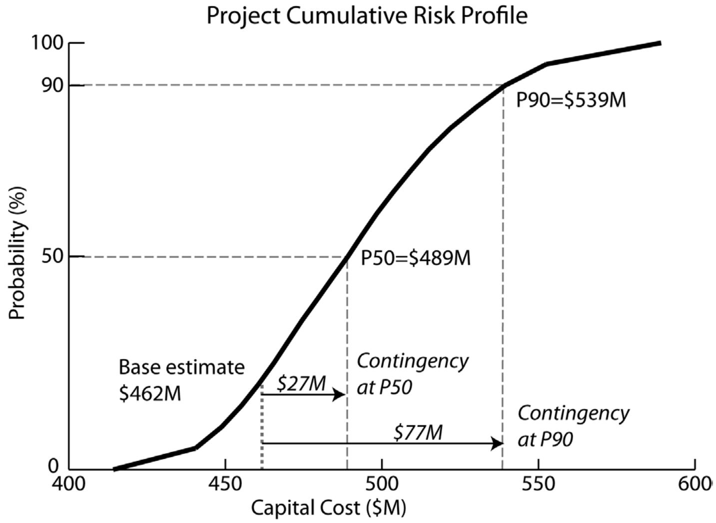

FIGURE 4–1 An example of the output from the Monte Carlo simulation of a capital cost estimate. *Source: Mike Fontaine.*

duration or end date. This analysis is used to establish the additional float to be included in the schedule based on the risk threshold established for the project (i.e., probability of meeting a certain project end date). The additional float is normally shown as a single activity at the end of the schedule.

The additional float to be included in the project schedule affects the capital cost estimate, because any increase in project duration will increase fixed overhead costs, such as project and construction management. After analysis of the schedule has been completed, similar analysis of the capital cost estimate can be done. The result is the contingency reserve to be included in the capital cost estimate (Figure 4–1).

Figure 4–1 plots the cumulative probability of not exceeding the estimated capital cost versus estimated capital cost. In this example, the base estimate, the total deterministic direct and indirect costs excluding contingency, is $462 million. The median value (P50, or probability of 50%) from the simulation is $489 million, or $27 million greater than the base estimate. This means that there is a 50 percent chance that the actual project cost will be less than $489 million. If the contingency reserve was selected on the basis of P90 (90% probability of not exceeding the estimated capital cost), one would expect the actual capital cost to be less than $539 million, $77 million greater than the base estimate, 90 percent of the time. Thus for the same project, the contingency reserve would be $27 million if based on P50 and $77 million if based on P90.

The probability used to establish the contingency reserve depends on the specific stakeholders involved in the project. A small company having only a single project in its portfolio, and for which the project represents a large part of the company assets, would tend to be more risk-averse and base the contingency on a probability closer to P90. The company would want increased cost certainty.

On the other hand, a large company having many projects in its portfolio, and for which a single project represents a small part of the company assets, would tend to be more risk-tolerant on any single project. A cost underrun on one project would offset a cost overrun on another project. This company would likely establish contingency based on a probability of P50.

During project execution, quantitative assessment is used to assess the estimated cost at completion and the estimated project completion date. As cost commitments are made, schedule activities completed, and purchase orders and contracts closed out, the ranges on those elements go to zero, for there is no uncertainty or risk on those elements. Normally, the cost and schedule simulations are run quarterly, during project execution.