THE NEED AND PRACTICE OF DESIGN RISK ASSESSMENT

Prepared by Gary James FIEAust, CPEng, Specialist Consultant Bulk Materials Handling.
Presented by Chris Walker FIEAust, CPEng, Manager Western Australia.
Bechtel Services (Australia) Pty Limited.

SUMMARY

This paper provides an insight into some of the tools used to evaluate financial risks and hazards in conveying of bulk materials. The techniques can be applied from the proposal stage of conveyor design through to the operations and improvement of mature plant. As the subject is very large, and the tools generally used by experienced people with specialist training, this paper provides an overview only, with the aim of generating reader interest to seek out specific training or experts on the subject. As noted, the techniques can be used at various stages of any mining project, in this case the paper looks at risk analysis of budget estimates and hazard studies during the design phase. A good starting point for the set up and implementation of a risk management process is Australian Standard AS/NZS 4360.

1 Risk Analysis of Budget Estimates

1.1 Discussion

An estimate by definition predicts the cost of a project, but predictions contain uncertainties and are never 100% accurate, particularly given that only around 5% of engineering has been completed for a Commitment and Funding Estimate, much less for an Order of Magnitude and Economic Feasibility Estimate. An Order of Magnitude Estimate has an accuracy no better than 30%, the accuracy increases through an Economic Feasibility Estimate and the accuracy further improves to a Commitment and Funding Estimate, prior to project execution.

An estimate risk analysis is undertaken to determine the amount of money that is to be added to the estimate based on the probability of these uncertainties occurring. The purpose of the risk analysis is to:

- Provide a rigorous approach to risk assessment, and
- Appreciate the major risk elements and thus identify opportunities for risk minimisation.

The project's customer should be involved in the estimate risk analysis by contributing to and understanding the process, and consequently 'buying-in' to the outcome.

All studies/estimates that are prepared have inherent risks associated with the engineering solutions and costs as prepared during the Feasibility Study phase of a Project. The following list is not exclusive to conveyors. The risk analysis determines an amount of money, which may be spent due to the risks on a project. These would include:

- level of detail of scope of work,
- the level of engineering completed at the time of the study (generally around 5% for a Commitment and Funding Estimate, less for other levels of estimate),
- technical risks, eg
  - untried or "out of ordinary" process items,
  - flowsheet does not work therefore plant modification required
  - Civil failures, slips, swamps or cut in rock on overland conveyors, quantity take-off detail,
- budget pricing details for materials and equipment;
- labour costs and labour productivity,
- market conditions,
- construction schedule issues,
- unexpected changes in market conditions, eg:
  - changes in employee relations - labour productivity, wage rates,
  - material availability and cost, and
  - unexpected increases in escalation, exchange rates, say on belting from Germany or Japan

- contractual claims (all claims except for latent Conditions such as force majeure which is covered below),
- errors in the estimate,
- offshore unknowns, eg:
    - lack of knowledge on labour productivity, skills and workforce culture,
- force majeure - this risk is limited to consequential cost increase only because the increase in direct cost is normally covered by insurance,
- changes in government requirements, eg:
    - changes in environmental standards, tax laws
    - land title issues
- project delays and schedule changes uncontrollable by the EPCM Manager, eg:
    - project 'hold-up' due to access road or lease problems
    - major wet season disruption,
- additional safety requirements, and
- validity of geotechnical and engineering concepts upon which the estimate is based.

The method often used in the quantification of risks in large conveying projects is the Monte Carlo simulation, with most risk analysis software currently available being based on this technique. There is not, however, a common approach in the industry for the identification and quantification of variables which are used as the inputs into the Monte Carlo simulation process. Indeed, the mathematics used for risk analysis varies significantly from company to company, with a resulting broad range of methodologies and results. The output of Monte Carlo simulation and hence the risk amount depends to a great extent on the detailed methodology and mathematics used.

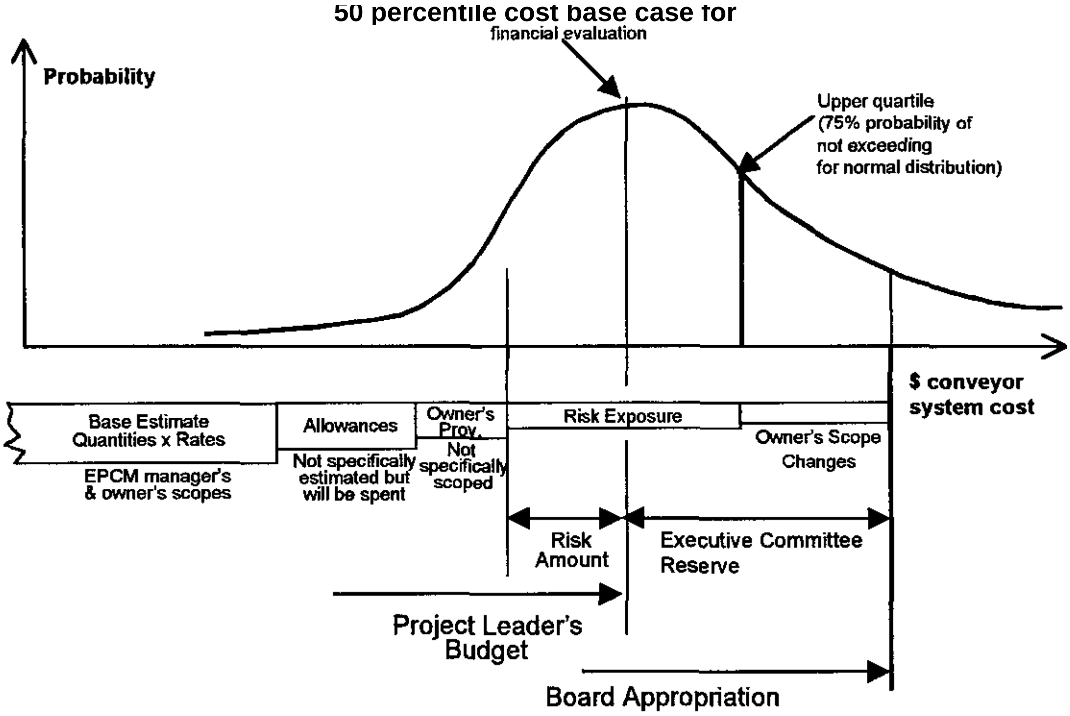
Minenco has developed a systematic and mathematically justifiable approach to the analysis of risk, the methodology of which is detailed below.

1.2 Risk analysis process

Before the risk analysis process can be started, an estimate must have been completed which includes the following items:

- development of a code of accounts or work breakdown structure to organise the
- estimate into logical groupings of costs,
- quantities prepared by engineering against a given scope of work,
- the estimate prepared by experienced estimators,
- addition of allowances as necessary by the estimators in conjunction with the engineers,
- estimate checked for integrity by engineers and estimators,
- a review of the job review carried out; and
- an estimate (often but not always) for escalation during the construction period prepared.

1.3 Risk Assessment Model



Risk Assessment Model

The model is designed to replace the concept of applying contingency (to allow for unknown items) with two separate elements within an estimate, namely:

1. **Allowances,** which are part of the estimated amount, and are determined by experienced judgement of the deficiencies of quantities shown in engineering drawings that are not fully detailed. Allowances are funds that are expected to be spent.

2. **Risk Exposure Amount,** which is added to an estimate to cover the unforseen needs of a project, which are beyond the control of the Project manager and Owner. The risk amount may or may not be spent.

This model can be used on most commercially available risk analysis software.

1.4 Steps

Following a review of the job, the Risk Analysis is carried out using the following five steps:

Step 1: Split the project cost estimate into a number of elements.

Step 2: Identify the independent variables that affect these cost elements and prepare a matrix of the cost elements and independent variables.

Step 3: Quantify the uncertainty associated with each variable. Eg.

	Minimum (10 %-ile)	Most Likely (50 %-ile)	Maximum (90 %-ile)
Belting cost probability distribution (As proportion of most likely)	0.95	1.00	1.15

Step 4: Run a Monte Carlo simulation and generate a distribution of total project cost estimates.

Step 5: Analyse the simulation outputs and quantify 'risk amount'.

2 Hazard Studies *2.1*

Discussion

Humans are strange creatures. We find it difficult to communicate, we take risks, we push things to the limit, we get tired and we make mistakes, we cover things up, we only report good news, and we believe in the security of safety devices etc. We know our faults. We have so many, that when operator error is blamed, it seems perfectly reasonable.

A few examples:

- An example of pushing things to the limit is ABS brakes on cars. Studies have shown, that with ABS brakes we travel faster, have more roll overs, often swerve too hard, because we can, we end up out of control. There is more chance of being shunted from behind. There are benefits, but the net effect appears to be slightly negative. The problem is the human factor. We adapt and push the limits further.
- There are a number of farmers who have been seriously burnt, late at night, looking into a tractor petrol tank with a cigarette lighter. Operator error? If the tractor had very fine mesh gauze over the inlet, a fire, or explosion would not occur.
- A vehicle workshop had a rectangular pit in the middle of the room. There were access doors each side of the pit to an office and a store. When passing through the workshop, from the office to the store, the mechanic had a choice of walking around the pit or jumping over. The norm was to jump; the mechanic slipped and broke his back. Operator error? This is the human factor at work again. Because we are human we can adapt, take short cuts, we minimise time etc. This has benefits, but it can often lead to disasters. If we understand the human factor, we can protect the human from these types of hazards. For example, if the layout of the workshop did not have the doors each side of the pit, the clever mechanic wouldn't be jumping and would still be walking today.
- The report by Department of Mineral Resources New South Wales, Summary of Mine Conveyor Accidents In NSW Coal Mines June 1995, shows that the two main causes of lost time and serious bodily injuries are, activities related to cleaning and maintenance and safe access. The "human factor" is at work again.

A number of hazards can be eliminated during the design process. Design procedures and rules etc can be developed to capture common issues. The procedures should be refined overtime using a process of the hazard identification, risk assessment and the development of suitable controls or application of a hierarchy of safety controls. For example, accident records show that ladders are dangerous. They can be replaced with stairs or lifts, and or the activity can be lowered to the platform/ground level. The use of stairs and lifts on large haul trucks and earthmoving equipment is now common.

During the design process the focus is on creating the facility in accordance with scope, criteria, procedures, budget, schedule etc.

The designers will not identify all the hazards, so their work must be challenged. This is the purpose of the Hazard Study. The aim is to challenge and apply a hierarchy of safety controls.

In a hazard study, the planned facility Is put under close scrutiny. Tools are used to discover the hazards and therefore improve safety, plant reliability and performance. The hazards are not only applicable to worker safety. Incidents affect the environment, company image, and relations with external parties and profitability. A major incident could put a company out of business and mean imprisonment or substantial fines for some participants.

The hazard study team needs to draw on extensive experience from a broad range of industries. Experience in one company or one site may not be adequate. The study team needs access to a good database on injury rates and incidents, causes and classifications, i.e. Catastrophic loss of process facilities is not a common event. So, using personal experience would have limited benefit. A simple way to inject this depth into the team is to engage an experienced facilitator, combined with members from similar operating plants, with a variety of experiences. That is, most often the process is qualitative and team based.

Hazard studies should be done during all phases of a project. In the feasibility stage, say during an early study when the details are broad, the hazard study would take a helicopter view of the project. For example, the process to be used, the siting of fuel storage, pipe lines, cable bridges, explosives stores and the route taken by vehicles with hazardous materials, security, emergency response, plant layout, road layout, maintenance philosophy, industry experience with equipment, utility failures, external influences etc. As the level of engineering detail increases, so does the detail of the hazard studies.

2.2 Risk

How do you determine if the risk of a hazard is unacceptable? For a start, concentrate on the important and put to one side, hazards that do not have a consequence of interest. These should be revisited later, ie. Do you only worry about losses larger than $10,000, $1M or whatever? The consequences of interest should be defined at the beginning of the hazard analysis process.

When considering risk, the important equation is:

Risk = Likelihood X Consequence

Likelihood is the rate of events per unit time ie years
Consequence is the loss per event, ie dollars, mass of material, deaths etc

A matrix can be used to investigate the consequences of interest. Refer to AS4360. For example: (A, acceptable; M, Moderate; U, unacceptable)

L	*Very high*	**A**	**M**	**U**	**U**	**U**
I	*High*	**A**	**M**	**U**	**U**	**U**
K E	*Medium to high*	**A**	**A**	**u**	**U**	**U**
L I	*Low to medium*	**A**	**A**	**M**	**U**	**U**
H	*Low*	**A**	**A**	**M**	**M**	**U**
O O		*Low*	*Low to medium*	*Medium to High*	*High*	*Very High*
D	**SEVERITY OF CONSEQUENCE**					

Alternatively, a risk curve can be created, by taking the Log of a measure of likelihood and consequence.
Either way, the values used in the matrix are peculiar to an operation and require a team approach for development. The matrix is not applicable for law, code, and policy type of issues. For some issues any frequency of occurrence is unacceptable. The matrix approach doesnt encourage the lowering of the accepted levels of risk. It is also difficult to combine issue types on a common scale. Ie. Environment, economic etc. It also requires judgement and experience.

2.3 Hazard Evaluation Plan

Before using any of the tools, the process to be followed should be defined and cover issues such as:

- Experienced expertise
- Preparation required, team selection, data gathering, pre-work
- Strategy
- Meeting rules, mechanics
- Schedule
- Scope definition
- Update frequencies
- Required content of reports
- How recommendations are handled, resolved, actions, rejected
- Cost benefit analysis
- The tools to be used

2.4 Tools

The following are some of the tools that can be used:

What if Checklist WI/CL

A loosely structured brain storming technique. These methods go through a series of what if questions or a check list, to identify hazards. It can be applied to a proposed conveyor design as well as operating procedure for the same and has the ability to take into account human interaction. (For example, what if the material runs backwards down the belt?).

Failure modes and effects analysis FMEA

This is a structured method that looks at the impact of equipment and component failures on the system performance. If you have failure statistics on the components this method can produce quantifiable results and be used to develop a maintenance strategy. (For example, if a conveyor oil cooling pump fails, or a belt slip sensor, or over pressure valve or alarm fails.)

Hazard and Operabiiity Analysis HAZOP

This technique looks at all the ways equipment can malfunction or be used incorrectly. It is most easily used in fluid processes based on detailed Piping & Instrumentation Diagrams or Process Flow Diagrams. The method stimulates the thought process by using trigger words applied to process variables at each section of the process such as; Flow is less than, more than, reverse etc. This is a rigorous process that can sometimes miss out the non-process related human interaction.

Event Tree Analysis ET

This process looks at the possible system responses to an initiating event. It lists the outcomes and allows judgements of the possibility of each. The tree starts at the initiating event, and then branches when each level of protection is challenged with a yes no response. (Or success/failure). For example, there is a leak from a hydraulic line, does the system shut down? yes no. If no, does the containment system work? Yes no, If no, is the any ignition source? Yes no. etc.

Fault Tree Analysis FT

This technique looks at the failure sequence / tree, using logic symbols. It commences with the outcome and looks at the faults that in turn produce this. Again the process is aimed at identifying failure modes that haven't been considered.

Starting with the top of the tree, say the failure mode of interest is a dosed valve. The method works back down the tree using logic symbols, looking at all the inputs that would cause the valve to be closed.

A natural human response, when an unsafe condition is identified, is to add a protection device, to eliminate the condition. The tools are used to consider what happens when the device fails. For example, the relief valve fails to work, the vessel sees overpressure, then explodes and destroys the power station, and lunchroom. The hierarchy of controls used to overcome this problem would be to, eliminate, engineer a solution, substitute, create procedures, personal protective equipment (PPE).

Each of the tools has benefits and limitations. There are a number, so the detail is not covered in this paper. As in the application of all tools it is preferable to employ somebody trained in a tool to use it. The tool should be selected for the task based on the complexity of the project, perceived risk, nature of the plant, stage of the project availability of a trained facilitator and experience of the organisation with the process or facility.

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AUTHORS

Principal Author

Gary James FIE Aust CP Eng

Gary has 22 years of experience in engineering in the mining and minerals processing industry developing a specialist expertise in Bulk Solids Handling.

Gary was a senior engineer on the Channar iron ore project for Hamersley Iron and the People's Republic of China. He was responsible for estimates and preliminary design on a project which included several in-plant conveyors and two 10 kilometre long overland conveyors with a capacity of 10 million tonnes of iron ore per year. This design work included a selection of belting, idlers, pulleys, reducers, brakes, and other mechanical equipment.

Gary was senior mechanical engineer on Bougainville projects, which included the selection of crushers, screens, grizzlies, and apron feeders on the preconcentration plant. The work also included the design of several kilometres of high capacity conveyors. Work also included design and specification work for the Mount Thorley Coal Mine including design checks for the stackers and reclaimers, involving review work in Germany.

Gary's experience in smelters includes design and project management work on the Stage Four expansion of the New Zealand Aluminium Smelters Limited aluminium smelter at Invercargill, New Zealand. This project included materials and equipment for the new potline and gas handling system. Other process plant work in which he has been involved includes design of the butt bath crushing facility for Comalco at Bell Bay.

His most recent world class project was design of the Kaltim Prima Coal 13 kilometre long, single flight conveyor in East Kalimantan Indonesia. The technical specifications and contract documentation for erection of this conveyor were prepared by Gary together with the provision of assistance in the development of static, dynamic, and horizontal curve conveyor programs. He also prepared technical specifications for the coal preparation plant and coal handling facilities at Kaltim Prima. Papers written in regards to his experience on this project have been delivered at conferences and published in international journals.

Gary was a committee member of the recently published Australian Standard AS 4324 :1995, Mobile Equipment for Continuous Handling of Bulk Materials, and is Victorian Convenor of the Australian Society for Bulk Solids Handling.

His role is Specialist Consultant Materials Handling in Bechtel Australia and currently responsible for the Large Mobile Machines on the Port Waratah Coal Services upgrade project in Newcastle NSW.

Presenting Author

Chris Walker FIEAust CPEng

Chris has 30 years of experience in the smelting, mining, and power industries and engineering project management. His expertise covers electrical engineering design, operation, maintenance, construction and project management as well as technical and business consultant roles. He worked for several years each in an aluminium smelter, on a nuclear power station commissioning project and a copper/nickel mine and smelter. These were located in Tasmania, the U.K. and Botswana respectively. In engineering design and project management he worked on various industrial and mining projects. These include the Argyle Diamond Mine, the upgrade of the Worsley Alumina Boddington Bauxite Mine Apron Feeder and Primary Crusher ROM Dump Hopper, an aluminium Extrusion Press Facility, Tom Price Iron Ore No.2 Primary Crusher electrical upgrade and Salt & Gypsum mining plant improvements.

He has been actively involved in the recruitment and professional formation of young engineers and holds a personal interest in this area.

Recently he has been responsible for the Hazard Analysis and Estimate Risk Assessment of projects covering design, in-plant improvements and upgrades and plant closures in the mining industry and has presented papers on this topic.

He is currently Manager of the Bechtel Australia, Western Australia Office.