RISK WEIGHTED CASH FLOW, A COMMUNICATION TOOL FOR ENGINEERS AND FINANCIAL PROFESSIONALS ON NEW TECHNOLOGY PROJECTS

*Mark Kennedy[1], Cameron Harris[2], and Allan MacRae[3]

[1]Norwegian University of Science and Technology
Materials Science and Engineering
Alfred Getz Veg 2B
Trondheim 7491
Norway
*(*Corresponding author: mark.kennedy@material.ntnu.no)*

[2]SNC Lavalin Inc.
Mining & Metallurgy
195 The West Mall
Toronto, ON M9C 5K1
Canada

[3]MacRae Technologies, Inc.
1000 Silver Maple Lane
Hayward, CA 94544-6681
USA

ABSTRACT

New technology projects, particularly those involving first-of-a-kind metallurgical facilities, have a poor track record of achieving their overall financial targets, as they incorporate technological risks in addition to normal project risks.

Traditional project management tools focus on risk from concept development through implementation, but typically fail to address the additional risks associated with a new technology project including slow start-up, slow ramp-up, and failure to achieve design performance (quality or throughput). These additional risks affect future cash flows produced by the project and hence its value, typically measured as net present value (NPV) or internal rate of return (IRR).

Common accounting practice is to reduce the present value of future cash flows by applying a chosen discount rate, often reflecting the corporation’s cost of capital. This discount rate does not contain an allowance for technological risk, which is often underestimated or misunderstood by both the financial and engineering project managers.

This paper will focus on the topic of project risk and new technology, and how these play a role in the probability of achieving the predicted future cash flows. By properly addressing technological risk in the form of risk-weighted returns, marginal projects can be prevented from proceeding, while sound projects can be given the additional time and resources required to achieve the optimal level of front-end-loading (the level which returns the maximum risk-weighted net present value).

A simple set of mathematical tools should enable engineers and financial professionals to establish a common level of understanding, thereby leading to a more accurate assessment whether a new technology project is ready to pass through its next level of approvals.

INTRODUCTION

When engineers work together with financial professionals to realize a major new metallurgical facility, the primary objective is a functioning profitable business unit, a unit which produces an adequate financial return in a safe, legal and environmentally responsible manner. The performance of a project is determined by the extent to which targets are achieved in a number of areas under the direct influence of engineers, such as those listed in Table 1.

Table 1 – Some key project targets influenced or controlled by engineers

1.	Capital cost
2.	Operating costs
3.	Schedule
4.	Safety
5.	Environment
6.	Plant throughput
7.	Online time
8.	Product quality
9.	Product price (by achieving customer specific physical and chemical properties)

With the rapid pace of technological progress, it is inevitable that new technology is incorporated into projects in an effort to improve the performance relative to the above list, and thereby achieving higher rates of return. Some projects are so novel that without new technology, they could not be executed at all. The inclusion of new technology carries additional risks, which if not carefully controlled, can reduce the probability of success in many of these key project areas. One standard method of addressing these risks and increase the probability of financial success is to "Front-End-Load" (FEL) the project [1-2].

New technology projects require a higher level of FEL than standard projects in order to achieve a similar risk profile. This extra FEL work requires additional time and resources, and consequently cost, at an early stage in the project's financial life where the cost impact is greatest due to the absence of any significant discounting. The extra time and resources applied to FEL show up as a reduced Net Present Value (NPV) or Internal Rate of Return (IRR), unless the calculations take into account the change in financial risk. Without a correct appreciation of the relationship between technological and financial risk, the value of adequate FEL is not revealed and undue pressure may be placed on engineers and constructors to 'fast-track' projects. Projects progress through stage-gates too early and the project's financial performance can suffer.

There appears to be a strong motivation to develop a standard method of incorporating risk or probability into these analyses. This methodology will be equally applicable to technological risk associated with the adoption of new technology, as well as the usual technical risk which exists within every project, such as the degree that test samples are representative of the production plant feed or the impact of the simplifications of thermodynamic modelling as compared to the real world chemical reactions and solutions.

This paper will:

1. explore some of the sources of technical and technological risk in the context of metallurgical projects and their impact on some specific areas of plant performance, namely start-up, ramp-up, safety and ultimate plant throughput as a percentage of the original design,
2. examine a generic case study to better understand the issues, and
3. propose a simple communication tool designed to increase the probability that the engineer responsible to execute a project involving new technology is given the time and resources to do so with an acceptable level of technical and technological risk.

TECHNICAL AND TECHNOLOGICAL RISK IN METALLURGY

Technical risks exist in metallurgical projects even in the absence of 'new technology'. Technical and technological risks are similar. They overlap, interact and often compound each other's effects. Technical risk is defined in this paper as the risk that the designed process equipment is not fit for purpose, due to project specific issues, such as size or composition of feed material, project location or selection of inexperienced suppliers. Technological risk can be present in the form of new processes or products, scaled-up equipment designs, first of a kind prototypes, or completely new technology [3].

The track record of projects in extractive metallurgy incorporating major new technologies is not a particularly good one. Relatively recent experiences, for example in pressure acid leaching of nickel laterites [4], clearly indicate how difficult it is to execute such projects on time and on budget, and then commission and ramp them up to their design capacities. For example, a comparison between the metallurgical industry and the chemical processing industry could raise the question, "Why are we unable to achieve a similar level of technical success?" A source of our difficulties can often be found in the nature of our raw materials.

Technical Risk

Edward Merrow [5] studied the relative performance of plants that primarily process solids and those that do not, for a fairly limited sample size of 60 plants. He found that the average performance of plants that process no solids was 84%, while the performance for solids processing plants was only 63%. Performance was defined as percentage of design throughput measured 6 months after start-up. This effect is shown in Figure 1.

In a later publication, Merrow [6] used a much larger sample size of 508 plants, and examined the impact of the nature of the raw material on both "operability" measured from 6-12 months after start-up, and ramp-up (Figures 2 and 3). Plants treating a natural solid raw material as feedstock have a significantly lower operating performance than those treating all other types of feed. Merrow concluded that variation in physical and chemical properties are at least partly responsible for sub-design performance. The metallurgical industry suffers in part from the nature of the feed stock. Each rock in a mine or each grain of concentrate is unique; hence metallurgical feeds are characterized statistically. The potential variability in liquid and gaseous feed stocks properties are significantly less by comparison.

The effect of solids processing can also be seen in the performance of their respective engineering projects. Projects for facilities that process solids experienced 12% more growth in cost after the project authorization and had their schedules slip 6% extra, when compared to plants that processed only gas and liquid [6].

It can be argued that technical risk is highest for projects directly treating raw ore, for example in the production of ferro-alloys. Projects of this type can greatly benefit from efforts to both quantify and reduce natural variations in the feed, e.g. adequate ore blending and mine planning. Figures 2 and 3 show that processing a refined solid feed stock, with reduced chemical and physical variability improves the ultimate throughput and reduces ramp-up time. Examples would be the use of smelter grade alumina in aluminium production or the use of concentrate in copper smelting. Hence, shifting from raw ore to concentrate smelting would be an example of reducing technical rather than reducing technological risk.

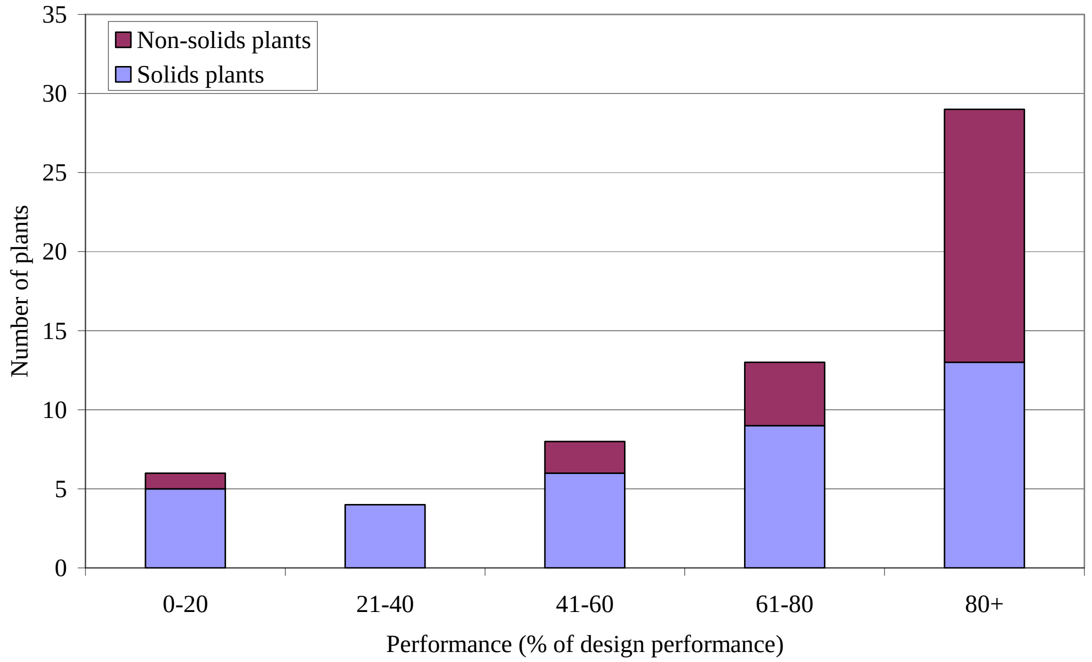

Figure 1 – Relative plant performance for solids and non-solids processing plants [5]

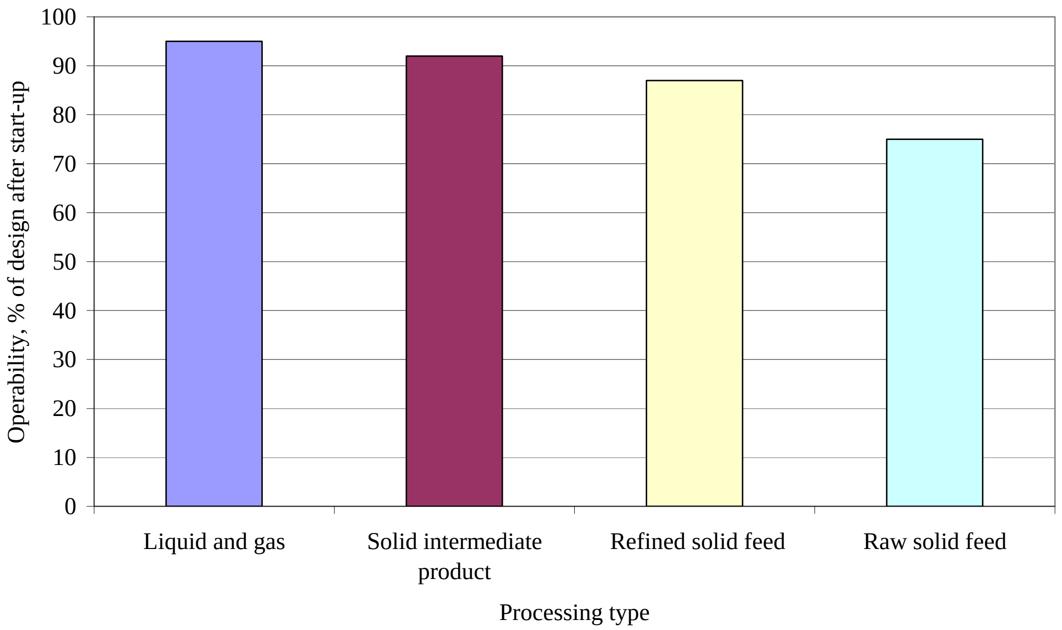

Figure 2 – Proven technology plant capacity as a function of raw material type [6]

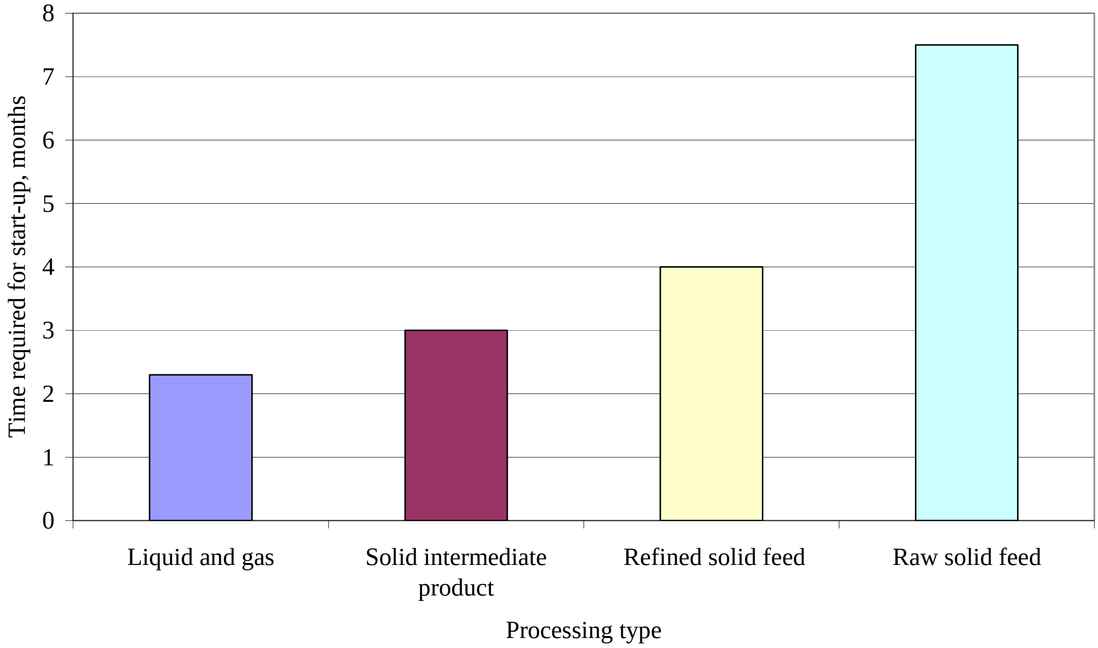

Figure 3 – Time required for start-up of plant by type of feed [6]

New Technology Risks

<u>Performance Risk</u>

New technology risk is distinct from and additive to technical risk. Merrow [5] explored the impact of new technology in solids processing plants. He examined the degree of innovativeness and risk of new technology (independent of raw material type) by quantifying the number of new technology steps in series and correlating plant performance with increasing number of steps in the range of 1-5 and found (for a sample size of 38 plants):

$$\text{Performance (\%)} = 88 - 18 * (\text{number of new steps}) \qquad \text{with } R^2 = 0.6 \qquad (1)$$

Above four new process steps in series, Equation (1) returns zero output. Note that Equation (1) has a relatively low R^2 value, as it does not include the effect of feed type or the quality of the project execution on plant performance. Merrow [6] also reports that "A highly innovative solids-processing facility commonly requires 24-60 months to reach complete steady-state operation at the original design rates."

The difficulties in dealing with large numbers of new processing steps are likely caused by the exponential nature of the number of possible interactions between steps. Beyond two or three new steps, it becomes increasingly difficult for an engineering team or project manager to assess the possible interactions. A prudent engineer will prioritize the process steps that can most benefit from new technology, and seek to minimize where possible the number of new steps. Projects requiring three or more steps using new technology would require, as a minimum, a complete integrated demonstration scale plant to achieve an acceptable level of risk. Those with five or more should probably not be attempted at all without exceptional levels of front-end-loading and the existence of significant financial incentives.

Ramp-up and Performance Risk

McNulty [7] explored the interaction between technology and actual plant performance measured 6 months after commissioning, as shown in Figure 4. Projects were characterized into four ‘Series’ depending on the nature of the technology and the quality of the project execution:

Series 1 – Mature technology, standard equipment and/or thorough testing
Series 2 – Prototype, first licensee, first-of-a-kind, insufficient front-end-loading
Series 3 – Limited testing, poor characterization of feed, ‘fast track’
Series 4 – Little continuous testing, too much ‘value engineering’, very complex flowsheet, poor fundamental knowledge, poor direction from corporate management, failure of the owners to take responsibility for their project, lack of attention to the feed materials, poor preparation of design criteria, lack of safety margins, etc.

Fast track and new technology should never be pursued simultaneously. McNulty would characterize such projects as falling on Series 4 or below.

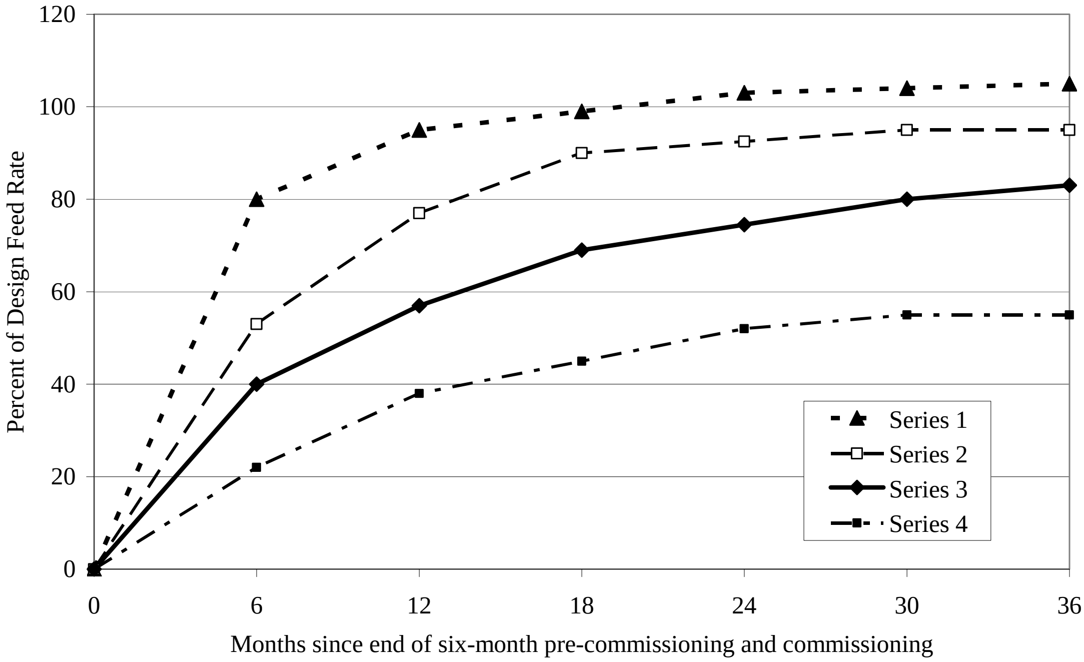

Figure 4 – McNulty’s ‘Series’ concept for technologies [7]

There are significant similarities between McNulty’s Series concept and the assessments of Merrow. Comparing these two systems, a non-solids processing plant is typically Series 1, whereas the average solids processing plant is often Series 1 or 2, before new technology effects are included. A solids processing plant with two new process steps would be Series 3, and with three new steps would be Series 4. Imrie [8] and others [4] have explored the Series concepts in relation to recent metallurgical developments.

Design Criteria for New Technology Projects

In a project using proven technology, the best source of design criteria is an operating plant using the same feed material and processing equipment. The worst source is a guess. In the case of new technology, industrial benchmarks of similar applications are of limited value or possibly non-existent. A key issue in new technology projects is the quality of the design criteria. McNulty [7] identifies poor design criteria as a key feature of Series 4 plants, i.e. "Translation of the test work to design criteria was flawed." A major focus of a new technology development program must include execution of test work with the primary objective to produce the correct design criteria for future project stages. In order to achieve this goal, it is necessary to 'think forward' to the design criteria required for the next stage of execution and plan the test work accordingly. Ultimately, pilot plant or demonstration scale tests should be conducted with a plan to deliver the key process design criteria required for final project engineering. If this is a task performed 'after the fact', for example during the basic engineering phase by an engineering firm, then key process and equipment design data will be missing.

Design criteria are not all of equal value. Some design criteria have a much greater impact on the cost drivers of the project or the value of the future cash flows, and will have a direct connection with the project targets, as summarized in Table 1. It is vital to ensure that these 'critical to success parameters' have sufficient definition to minimize the risk of a design error. Many standard project management tools support a systematic approach for identification and management of such parameters, including: Six Sigma or Design for Six Sigma [9], FMEA [10-11], and risk registers.

Once these key design criteria are identified, the quality must be validated and the data/design improved where necessary. Benchmarking, test work, or more detailed engineering design can be used to gather better quality data, reduce the risk of error, and mitigate the consequences. The DMAIC methodology is one example of this philosophy and is shown in Figure 5. DMAIC must be applied during the concept/technology development and verifications phases of a project to have the greatest possible impact.

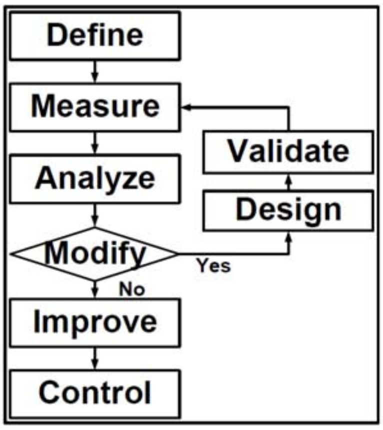

Figure 5 – DMAIC methodology for process problem solving [9]

Start-up Costs

Additional start-up costs are also associated with new processes, products and technology. Wallgrove and Butler [3] defined 'Start-up Costs' to be "non-capitalized owners costs from project inception through to some predefined production goal." Much of this cost is associated with the period after mechanical completion and before full production, refered to in Table 2 as 'Commissioning and Ramp-up' costs. These costs have been reported to be in the order of 6% of the total installed cost. However, if a new product is to be produced, they increase by a further 6% to 12%. For larger than normal equipment, another 3% should be added, and a further 5% added if prototypes are involved. If completely new technology is used, they are 10% higher again [3]. A new product being produced with completely new technology would have start-up costs estimated to be on the order of 22% of total installed capital. Given that these numbers are based primarily on the petrochemical industry, one would expect correspondingly higher costs for metallurgical plants taking into account the information presented previously in Figures 1-3.

Safety and "Unknown-Unknowns"

In reviewing a risk analysis, it is relatively easy to assess the quality or validity and effectiveness of the various identified risks and their mitigation efforts. It is not possible to assess the significance of issues that have not been identified and hence are missing from the analysis. Imrie [8] presented interesting examples about "known-knowns", "known-unknowns" and "unknown-unknowns" in terms of metallurgical design work. In a metallurgical project, an 'unknown-unknown' is an issue about which so little knowledge is available that the correct questions are unable to be asked, let alone speculation be made about the answers or allowances made for the risks. In the case of a project incorporating new technology, there is a larger opportunity for such unknown-unknowns to arise and hence a much greater need to front-end-load the project to shift these issues towards "known-unknowns". Using the example of copper cooling elements in furnaces, rather than suffer an unexpected explosion due to failure of water cooled copper elements, increased FEL may shift the level of knowledge to allow the question to be asked, "How long will the copper coolers withstand an unexpectedly corrosive environment?" The question, once asked, may lead to a defensible answer. Time and effort are both required in order to identify areas of missing knowledge.

The case has been presented in the previous sections for an appropriate degree of front-end-loading for metallurgical projects, and for increased levels in projects incorporating new technology. This approach is necessary to produce design criteria of sufficient definition to reduce technical and technological risk to levels where there is an acceptable probability of achieving the overall financial goals of the project. For projects with new technology, some members of interdisciplinary teams will lack direct experience with new technology commercialization. Review of this material and the associated references will establish the basis for clearer understanding of the varying degrees of FEL required for varying technical and technological risk.

CASE STUDY FOR A GENERIC 1 BILLION DOLLAR NEW TECHNOLOGY PROJECT

Taking the example of a generic one billion dollar new technology project beginning from concept through to the industrial plant at full production, it is assumed that the project will be 'well managed' according to standard industry practice [12] and that a staged project management approach will be taken, such as Stage-Gate® [13-15]. The project will need to meet fixed criteria in order to progress through each gate. The project will go through a number of gates in both the development and engineering phases after which it will proceed to execution. The decision to execute is typically taken after the feasibility study is concluded, and is based on a nominal project cost estimate with an accuracy of approximately -5 to +15% [16]. One financial criterion typically used for this gate is an IRR of equal to or greater than 15%, or a suitably high net present value using the corporation's average 'cost of capital' as the discount rate, which varies according to capital market conditions. It has been taken as 8% for this case study.

For the base case, an appropriate timeline must be selected. In metallurgical developments using new technology, 15 years is a reasonable assumption. In support of this assumption, two published examples of new technology metallurgical projects are offered. BHP Billiton's Ravensthorpe Yabulu Nickel project used six years and expended US$85 million to reach the decision point for the project, while Rio Tinto's HISMELT process is reported to have taken 21 years [17].

A summary of the life of this hypothetical project is shown in Table 2 and plotted in Figure 6. Values are based on experience with similar projects and typical literature data [16-17]. Financial risk in these figures is defined as:

$$\text{Financial risk} = (1 - \text{probability of achieving the desired cash flows}) * 100\% \qquad (2)$$

This concept is based on the financial consequences of 'freezing' the design criteria at any particular point in the project time line. It represents a simple, easy means of communicating the level of technical and technological risk.

Table 2 – Project summary for a hypothetical 1 billion dollar project from idea to full industrial production

Project Stage	Duration in years	Stage Gate	Approximate Percentage of Engineering Completed	Typical Accuracy of Cost Estimate	Percentage of Total Project Cost	Assumed Level of Residual Financial Risk, %
Idea	0	0				100
Preliminary Investigation and Analysis	0.5	1			0.01	90
Concept Definition	0.5	2			0.1	85
Concept Development	1.5	3			1.0	80
Technology Development and Verification	3	4			5	35
Scoping	1	5	minimal	-35 to +65	0.3	30
Prefeasibility	1	6	0 - 2	-15 to +50	0.4	25
Feasibility	1	7	5	-15 to +25	0.9	20
Budget Authorization	1	8	10 - 15	-5 to +15	1.8	15
Control	1		30 - 40	-10 to +10	3.6	10
Revised	1		80	-5 to +5	7.2	5
Construction	2				70	5
Commissioning and Ramp-up	1.5				10	5
Project Life Time:	15			Total:	100	

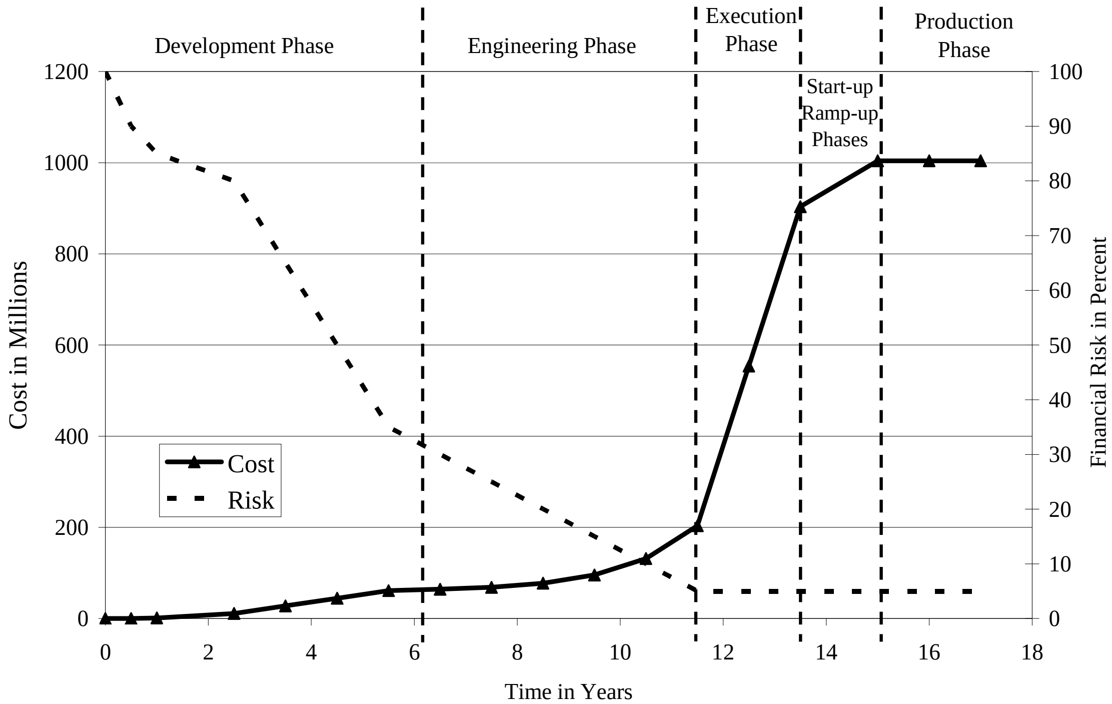

Figure 6 – Generic $1 billion new technology project life cycle

At the time an idea is first generated, there are no design criteria and the probability of successfully building a project or achieving any given cash flow is zero, hence Equation (2) would yield a project 'risk' of 100% as indicated in Table 2 and Figure 6. As the project continues, data is gathered from literature and any available industrial benchmarks. Laboratory, pilot and demonstration scale plants are operated. Engineering calculations and mathematical models are used to analyze the data and develop design criteria. There is a steadily improved definition to the design criteria and corresponding reduction in the financial risk factor that affects the calculated value of the future cash flows. The level of risk in a project approaches a minimum near the end of the engineering phase, assuming that overly aggressive 'value engineering' is not applied and no outright errors in design occur, creating unknown-unknowns. Five percent has been selected in Table 2 as an arbitrarily low, but non-zero, residual financial risk. These future cash flows can never be considered truly risk free.

It is extremely difficult to determine the quality of the information and to quantify the magnitude of the 'risk' at each project stage or stage gate decision point, particularly early in the project. However, provided that the overall concept of risk to future cash flows is accepted, some preliminary analyses can be made and all project members (both financial and engineering) will understand the necessity for further risk reduction. At later project stages, standard risk assessment techniques exist such as Monte Carlo simulation, which allow reasonable estimation of the possible ranges in outcomes incorporating better-defined deviations in inputs.

An examination of Table 2 and Figure 6 shows that the costs of early project phases are insignificant compared to the total project cost. The Concept Development phase typically costs only 1% of the total project investment. These early project phases can therefore be extended at low cost in order to achieve a higher level of project definition and a lower level of residual 'risk', i.e. extended to achieve a higher level of FEL. This concept is often shown in terms of a cost versus influence curve [17].

Financial Analysis

Many new technology projects are constructed on the basis that they are 'strategic' in nature and are associated with world class mining assets of high grade, large reserves, or both. The cash flows generated from such projects are determined by the life of the ore body and/or the metallurgical facility, which is typically longer than 25 years. Cash flows beyond 25 years have little impact on IRR or NPV, so 25 years has been chosen as a suitable calculation period for this analysis.

The base case values have been manipulated to give an IRR of exactly 15% assuming 25 years of positive cash flows, from the end of year 15 until year 40. The selected model parameters are included in Table 3. A simple NPV calculation has been performed assuming a discount rate of 8% and zero supplemental financial risk. Time zero is the point when the initial idea was generated followed by research and development that is undertaken before formal project study work commences. The base case assumption is that this plant is at exactly 100% capacity after 6 months of commissioning/start-up and 12 months of ramp-up. End of year is assumed for the cash flows. Production is assumed constant from the end of the ramp-up for the entire 25 year life of the project to simplify the calculations.

In addition to the base case, four additional cases have been calculated according to McNulty's Series 1-4 [7]. In Series 1, the project is executed as described previously, but is allowed to 'over achieve' its objectives in line with Figure 4. In the Series 2 case, the time line has been left unaltered, but 'savings' have been achieved by spending half as much on concept and technology development. In the Series 3 and 4 cases, the time line has been compressed or 'fast-tracked'. In the Series 3 case, the cost and duration of larger scale testing have been reduced by 50% and the scoping studies eliminated. In the Series 4 case, the cost and duration of the largest scale testing has been completely eliminated. In each case, the ramp-up curve of McNulty has been applied and the project performance is assumed to be fixed at the 36-month level of performance shown in Figure 4. The cash flows for each of these cases are shown in Figure 7 and the project's IRR and NPV are listed in Table 4.

Table 3 – Summary of inputs to the financial model

Laboratory-pilot scale: $10 million
Pilot-demonstration plants: $50 million
Engineering cost to feasibility: 3.4% or $34 million, (greenfield incorporating new technology [17]).
Total engineering cost: 10% or $100 million
Cost before project decision: $95.6 million
Commissioning and ramp-up owner's non-capitalized costs: 10% or $100 million
Fixed operating costs: $300 million/year
Production: 100 million units of product/year
Variable cost: $3/unit of production (total variable cost = fixed cost)
Value of product: $8.49/unit of production
6 month commissioning and start-up followed by 12 months of ramp-up
15 years from idea to full plant production
25 years of cash flows after full production achieved or 40 year base case project life
8% Discount rate for NPV

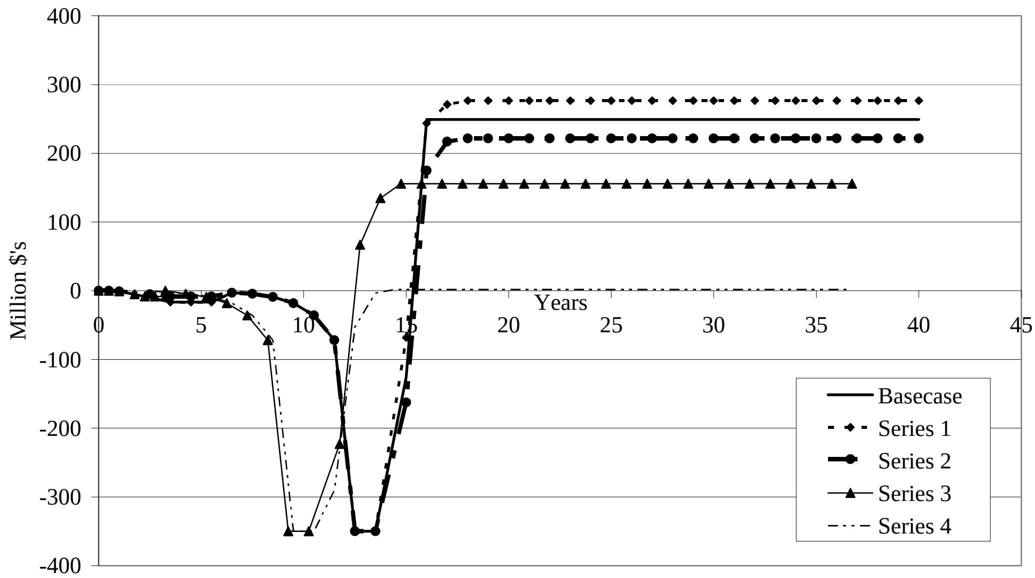

Figure 7 – Cash flow scenarios for a generic $1 billion dollar project

The 'benefits' in terms of the compressed project schedule and the time value of money do not appear, once the consequences to the plant performance are considered as shown in Table 4. The values in Table 4 show that the Series 3 plant is an economic failure and that the Series 4 plant will probably be closed. Series 4 has a negative NPV at 0% and an IRR cannot be calculated.

Table 4 – IRR and NPV for base case and Series 1-4 plants

Case	IRR (%)	NPV at time zero ($million)
Base	15.0	432
Series 1	16.5	536
Series 2	14.1	336
Series 3	9.7	106
Series 4	N/A	-548

Risk Weighted Cash Flow

Simpler financial analysis tools for new technology projects have been presented in the literature. For example, Boer [18] suggested the use of ‘probability of success’ to weight future cash flows. This base level of analysis is probably reasonable to apply in the conceptual development phases, prior to any clear understanding of the nature of the development, capital or operating costs. Four simple cases have been calculated assuming:

1. $1 billion dollar project cost is distributed equally over the first 15 years
2. a constant 40 year project life
3. a risk free cash flow (profit) of $249 million dollars per year for 25 years
4. a level of risk as defined below
5. risk adjusted cash flows

Risk has been determined in each case starting with the base financial risk of 5% from Table 2 and assuming a ‘linear’ consequence of project changes, e.g. a 50% reduction in expenditure on concept and technology development returns 50% of the benefit in terms of risk reduction. A ‘Series 1’ example that over achieves the project’s performance target has been arbitrarily assigned a risk of zero. Results are summarized in Table 5.

Table 5 – Risk weighted cash flows and NPV

Case	Financial Risk %	Risk Weighted Cash Flow, $million	NPV, $million
Base	5	237	225
'Series 1' over achieves production target	0	249	267
50% reduction in expenditure on large scale testing	30	174	16
Accelerated large scale testing and engineering	35	162	-26
No large scale testing	50	125	-152

A comparison between Tables 4 and 5 indicates that this extremely simplified methodology may be applied to early project decision making. A detailed study of the relationship between technological and financial risk at each project stage, as defined here within, might yield benefits in terms of decision making at both early and later project stages.

CONCLUSIONS AND RECOMMENDATIONS

1. Metallurgical processes with solid feed stock carry a higher level of technical risk than similar projects treating non-solid raw materials.

2. Technical risk is larger in those projects treating natural as opposed to pre-processed feeds.

3. New technology risk adds to the existing high technical risk prevalent in metallurgical processes.

4. Front-end-loading can improve the quality of the design criteria used in new technology projects and result in lower technical and technological risk and a higher probability of achieving the desired cash flow.

5. Engineers and financial professionals should agree on a methodology to define the magnitude of financial risk present at each project stage.

6. Applying both risk weighted cash flows and the time value of money should allow projects to reach better financial conclusions at each decision point and correctly determine whether additional front-end-loading is necessary to have a reasonable probability of achieving the overall financial goals of the project.

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