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Managing incomplete knowledge: Why risk management is not sufficient

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Abstract

The Project Management Institute's *Guide to the Project Management Body of Knowledge* (PMBOK) underpins many initiatives to improve project management practice. It is widely used for training and underpins the development of competency standards. Because of its fundamental importance, the PMBOK should be critically reviewed.

This paper agues for an expansion of the PMBOK Guide's risk management knowledge area to include a wider perspective of incomplete knowledge.

The PMBOK Guide deals with uncertainty through the traditional use of probability theory, however the underpinning assumptions of probability theory do not always apply in practice. Furthermore, probability-based risk management theory does not explain important aspects of observed project management practice.

This paper discusses an expanded framework of incomplete knowledge, including: an expanded concept of uncertainty that acknowledges ignorance or surprise, where there is no prior knowledge of future states; imprecision arising from ambiguity (fuzziness) in project parameters and future states; and, human limitations in information processing. The paper shows the expanded framework explains observed project-management practice more thoroughly than the probability-based framework. The conclusion reached is that "management of incomplete knowledge" provides a better theoretical foundation for improving project management practice.

To substantiate this, a promising new approach based on "real options" is also discussed. © 2001 Elsevier Science Ltd and IPMA. All rights reserved.

Keywords: Risk management; Uncertainty; Ambiguity; Human limitations; Real options

1. Introduction

Concern with uncertainty seems to grow as a field of knowledge matures. This has been observed in the evolution of physics, operations research, economics, financial management and a number of other fields. It is also happening with project management.

Practising project managers have long known that managing uncertainty is important, but formal recognition as a project management function has been relatively recent. For example, risk management was only separated into its own knowledge area in the 1986/87 update of the Guide to the Project Management Body of Knowledge (PMBOK[1]).

As with other fields of knowledge, it has been traditional in project management to deal with uncertainty by using probability theory. Whether by conscious design or not, probability theory also underlies the risk management knowledge area in the PMBOK and other references such as the national and international risk-management standards. Other fields, such as operations research and financial management, have expanded beyond the sole reliance on probability theory, and have recognised important aspects of uncertainty do not lend themselves to analysis by probabilistic methods. The same should apply to project management. Probability theory cannot deal with important aspects of project uncertainty and cannot explain some important aspects of observed project-management practice.

The main purpose of the PMBOK is to identify and describe generally accepted project management knowledge. [1, p.3] This paper does not claim that the theories and techniques herein are 'generally accepted'. However

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[1] For ease the term PMBOK is used in this paper to refer to the Guide to the PMBOK (PMI 1996).

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it shows the PMBOK is firmly rooted in a probability-based paradigm that limits its ability to explain actual project management practice. Limitations include the following:

- Probability theory is based on the assumption of randomness, whereas projects deal with consciously planned human actions that are generally not random.
- Projects are unique by definition. This reduces the relevance and reliability of statistical aggregates derived from probability-based analysis.
- Probability theory assumes future states are known and definable, however uncertainty and ignorance are inevitable on projects. Especially with regard to human actions, the future is fundamentally unknowable.
- We humans are limited in our ability to encompass and process the full range of information required for holistic decisions.
- Because uncertainty and ignorance exist, temporal aspects of the flow of knowledge are important in project planning. Probability theory is based on a two-period model that ignores the flow of knowledge over time.
- Project parameters and outcomes must be communicated to others and the imprecision of our language is not encompassed in probability theory.

Projects therefore require an expanded approach to incomplete knowledge. This paper aims to open up discussion about the value and usefulness of a broader approach incorporating fundamental uncertainty and ignorance, the theory of fuzzy sets and the temporal aspects of knowledge.

It is beyond the scope of the paper to expand on each of these theories. The paper therefore concentrates on the limitations of the probability-based approach and how an expanded approach could be used to better explain real-world project management practice. Finally, the options approach to project planning is discussed to demonstrate the value of the new theories.

2. Dominant paradigm

The dominant paradigm of risk analysis is undoubtedly the expected utility theorem that provides the foundation of probability calculus. Under this theory, the laws of probability apply if certain assumptions are met, including:

- Knowledge of probable future states.
- Rationality.
- Frictionless transactions.
- Random events.
- Repeatability.
- Comparability.
- Optimisation goal.

It is interesting to remember that probability theory arose from attempts to quantify the odds in games of chance. This heritage, with the associated set of assumptions, limits how the theory may be applied to other fields.

In games of chance the range of possible outcomes is perfectly known. For example take the throw of a die. The possible outcomes are represented by the set of discrete integers one to six. If one dollar is placed on a roll of a die the risk is precise... there is a one in six chance of a particular number turning up and the potential monetary loss is precisely one dollar.

Such conditions do not generally apply in project management. Relying on probability theory can mask other aspects of incomplete knowledge and can lead to a false sense of accuracy and precision. Consequently incorrect decisions may be made.

The applicability and consequence of these assumptions to project management is discussed below under the following headings:

- Randomness.
- Repeatability.
- Human limitations.
- Uncertainty and ignorance.
- The flow of knowledge.
- Fuzzy parameters.

2.1. Randomness

The assumption of randomness requires that each event is independent of all other events and that no knowledge passes between them. In live projects, this rarely applies. As Trigeorgis [2, p.130] states, managers face two types of uncertainty:

- Random variations in the state of nature (where the rules of probability apply).
- Non-random or specifically targeted actions and reactions made by human players (where the rules of probability do not apply).

Effective human interaction is vital to project success.[2] Human interactions are rarely random and involve all the positive and negative aspects of human nature including bias, spite, competition, loyalty, revenge and so forth. Human interaction is not noted for its randomness!

So while the traditional risk management approach applies to random events, applicability to project management is low. Therefore an expanded approach is

[2] For example see the discussion on the importance of communication skills below.

needed to incorporate the non-randomness that tends to dominate project management.

2.2. Repeatability

Most projects are unique endeavours and opportunities to reuse statistical information are limited. Knowledge gained from previous projects often does not generalise well to future projects. The tools of probability theory, which rely on historical knowledge, are of limited value in most project circumstances. As Shackle [3, p.5] states:

> 'The theory of probability, in the form which has been given to it by mathematicians and actuaries, is adapted to discovering the tendencies of a given system under indefinitely repeated trials or experiments. In any set of such trials, each trial is, for the purpose of discovering such a tendency, given equal weight with all the others. No individual trial is considered to have any importance in itself for its own sake, and any tendency which may be inductively discovered, or predicted a priori for the system, tells us nothing about any single individual trial which we may propose to make in the future.'

2.3. Human limitations

As Miller [4] summarised in his well know paper '*The Magical Number Seven, Plus or Minus Two...*', humans have a limited information processing capacity. It seems that about nine decision attributes is all that a person can effectively encompass at one time. Group techniques might broaden the perspective somewhat, but even still human information-processing limitations will often preclude optimal (holistic) decision making.

The traditional project management approach is to decompose problems into understandable chunks by work breakdown structures, functional decomposition, specification hierarchies and the like. These reductionist approaches help us cope with complexity, but they tend to destroy a holistic perspective of the project.

It is often beyond our capacity to comprehend a complete set of future outcomes (as required by the tools of probability), even though the information may be available in some form. Therefore in a very practical sense, fundamental uncertainty and ignorance are inevitable parts of project management. Project managers need something more than the tools of probability theory to deal with it.

2.4. Uncertainty and ignorance

There are several definitions of risk and uncertainty. One view, attributed to the seminal work of Frank Knight [5], defines risk as the form of incomplete knowledge where the future can be predicted through the laws of chance. That is where probability distributions of future occurrences can be constructed.[3] Uncertainty can then be defined as the variability of future outcomes where probability distributions can *not* be constructed.[4] Using these definitions, risk applies when there is repetition and replicability. Uncertainty applies when there is no prior knowledge of replicability and future occurrences defy categorisation.

By the very definition of a project being a unique undertaking [5, p.4], one would expect a large part of project management to involve uncertainty (as defined above). Indeed the limiting case of 'total ignorance' or fundamental uncertainty [3] often applies, where future states cannot even be imagined let alone defined. Both uncertainty and ignorance is poorly handled in probability theory.

2.5. The flow of knowledge with time

The assumptions underlying the expected utility theorem are based on a model with two time periods... the present and the future. In essence, probability-based analysis works this way:

- At Time Period 1 (the present), analysis of future states and their probability distributions leads to a rational plan of action that maximises expected positive outcomes.
- The plan is then implemented and the predicted consequences of the plan are realised at Time Period 2 (the future).

This two-period model falsely implies the role of a project manager is limited to analysis and planning. It assumes project management throughout the project is essentially passive. The project weaves through a predetermined branching path according to the states of nature encountered on the way. It also implies that once a project commences, the plan will be implemented unchanged because risks are known and remain constant.

It is a platitude to experienced project managers to say this does not reflect reality. Projects are by definition unique and knowledge of future states is limited. Project managers know that each stage of a project reveals additional knowledge and active, hands-on project management is needed to reassess project plans, to imagine new possibilities, to amend plans and to implement changes.

[3] Another view of risk is that it is the downside subset of uncertainty associated with calamitous events. This conflicting definition and other definitions cannot be pursued within the scope of this paper.

[4] It should be noted that several modern authors dispute Knight as the source of this definition but it serves this paper to use the distinction to portray the existence of different states of future knowledge.

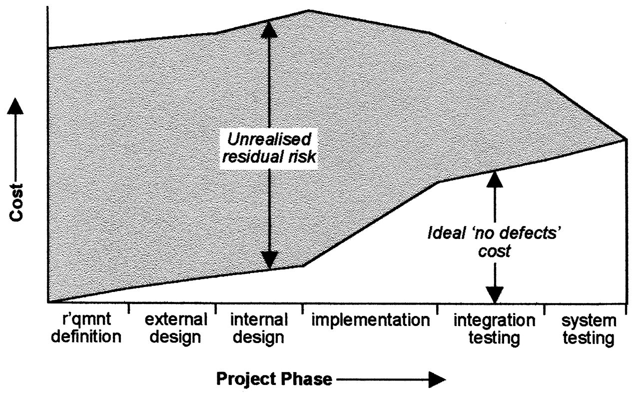

Fig. 1. Computer application development risks.

Typically, the uncertainty of a project reduces with time as more knowledge is progressively revealed. For example in the case of a mining project, the extent of the ore body and extraction considerations may not be known until core sampling and surveying has been completed.

Another example is shown below in Fig. 1. The chart shows the typical flow of planned costs and residual risks over the life of a typical large computer software development project.

The chart is made up of two curves. The lower curve represents the accumulating costs of the ideal outcome where the whole project is completed without any correction, rework or back tracking. The upper curve represents the extent of the possible rework faced at a given point in time. The shaded band between the two curves is an indicator of the uncertainty on such projects. Notice the uncertainty band starts large and diminishes in steps to zero at the close of the project.

In these circumstances, probability analysis is usually of limited value because the range of future states varies at each point in time, as additional knowledge is discovered. The PMBOK Risk Management Knowledge area and other guides relying on probability theory are deficient in not addressing the temporal flow of knowledge and uncertainty.

2.6. *Fuzzy parameters*

Risk and uncertainty are concerned with incomplete knowledge over the future 'states of nature'. It is often forgotten that probability techniques assume that decision parameters and outcomes fall into well-defined, mutually exclusive[5] categories. In reality vagueness and ambiguity exist, due to the limitations of our language and other factors such as context and mood. When a large number of people are involved the magnitude of the fuzziness increases.

Project parameters and outcomes have 'shades of grey[6]'. Take for example the following statements:

> "If the schedule slippage is very small and the design changes are great then the cost impact will not be insignificant."

> "The installation was a grand failure."

> "System performance is inadequate."

This type of statement often occurs in projects and reflects the true imprecision of project processes and outcomes. Enforcing more precise language (as with technical specification language) may merely create an illusion of precision. Imprecise statements cannot be interpreted within the framework of probability theory because of its assumption of crisp inputs and outputs.

The theory of fuzzy sets provides a framework and offers a calculus to address these fuzzy statements. Zadeh [6] states the theory of fuzzy sets:

> '... provides a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria of class membership rather than the presence of random variables.'

In the context of fuzziness we deal with the *possible* not only the *probable*. Possibility is the degree of ease with which a variable may take a value. Possibility describes whether an outcome *can* happen while probability describes whether it *will* happen. Unlike probabilistic categorisation, possibility categorisation allows overlapping, fuzzy sets where the truth (or believability) of categorisation is measured as a degree of membership falling between zero and one. For example a certain project outcome might simultaneously have a degree of membership of the category 'failure' and a degree of membership of the category 'substantial failure'. This is shown diagrammatically below in Fig. 2. Notice that Outcome 1 falls in both the category 'failure' and the category 'substantial failure' albeit with different degrees of membership.

Loose relationships between probability and possibility exist. For example lowering the possibility of an occurrence tends to reduce its probability but the reverse does not apply. Probability theory does not get

[5] Often the term "crisp" is used to describe unambiguous categorisation. (compare with the term "fuzzy"). The assumption of crispness comes from the gaming heritage of probability theory, already discussed.

[6] Zadeh used the term lexical elasticity to describe these shades of grey. See the forward to Dubois and Prade [7].

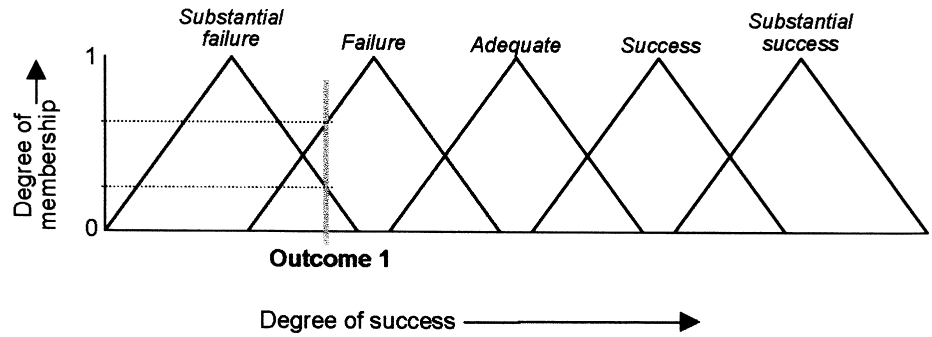

Fig. 2. Fuzzy categorisation of a project outcome.

displaced or even subsumed by the theory of fuzzy sets and the two approaches are complementary. Probability theory is good for crisp but dispersed information. The theory of fuzzy sets is good for fuzzy but coherent information [15].

3. Limitations of existing reference material

The PMBOK purports to reflect widespread project management practice. It aims to be a document for practitioners, not a theoretical reference. In this sense it should be theory neutral. This section shows how the risk management knowledge area is strongly steeped in the probability theory paradigm.[7]

In the PMBOK, the risk management process follows a cycle of:

- Risk identification.
- Risk quantification.
- Risk response development
- Risk response control.

Risk identification is based on identifying discrete occurrences of risk that may affect the project for better or worse. [1, Glossary p.169] By omission the process assumes that all risks are indeed identifiable. Nowhere does the PMBOK allude to the ignorance or the fuzziness discussed above.

The PMBOK section on risk quantification acknowledges difficulties in quantifying risk [1, p.115] due to imprecise or incomplete knowledge. This being the case, no systematic approach to overcoming the problems is given. For example statistical techniques such as statistical sums, Monte Carlo simulation and decision trees are discussed. Such analysis can involve significant additional expense and is only warranted in the rare instances where the assumptions of probability theory apply.

[7] The theory bias of the Guide to the PMBOK probably occurred by default rather than by specific intent.

These deficiencies may be a consequence of widespread, subconscious reliance on the probability-theory paradigm. Ignorance and fuzziness cannot be incorporated in the probability-based models and can only be dealt with as externalities in an ad hoc manner. For example the PMBOK (p.120) mentions contingency and multi-level reserves but offers no guidance on how to determine them and no guidance on when to exercise them.

There is nothing in the PMBOK that locks out an expanded view of incomplete knowledge but the language used and the scope of techniques included shows it is rooted in the probability-theory paradigm.

The Guide to the PMBOK is not alone in these deficiencies because other well-known references on risk management take the same limited perspective on knowledge imprecision such as:

- Standards Australia, 1995. *AS/NZS 4360:1995: Risk Management* [8];
- NSW Public Works Department, 1993. *Guidelines for Management of Risk* [9];
- Management Improvement Advisory Committee (MIAC), 1995. *Exposure Draft: Guidelines for Managing Risk in the Australian Public Service* [10].

4. Practical evidence supporting and expanded approach

This section describes aspects of observed project management practice that are better explained by an expanded perspective of incomplete knowledge.

4.1. Multi-layer reserves

Experienced project-based organisations often set aside a percentage of each project budget as a reserve for unforeseen events. Sometimes the reserve budget is split... some being under the control of the project manager and some being under the control of higher management.[8]

Reserve budgets implicitly acknowledge the existence of ignorance in projects, but there is no guidance in the PMBOK about how to form or control reserve budgets. An expanded perspective on incomplete knowledge would provide a firmer theoretical foundation for this practice.

4.2. Rolling-wave approach

The 'rolling wave' approach to projects is increasing in acceptance and practice. This approach recognises that firm commitments cannot sensibly be made on incomplete knowledge. Therefore binding commitments are phased to match the flow of knowledge.

Initially, firm (binding) commitments are only made on the first phase of the project, and budgetary (non-binding) commitments made on subsequent phases. As the project rolls through to the end of one phase, a firm commitment is made on the next phase and budgetary commitments for follow-on phases are reviewed. This can be visualised as a bow wave of commitment rolling in front of each phase.

As with multi-layer reserve budgets, the rolling wave approach implicitly acknowledges the existence of ignorance in projects. The probability-based approach in the PMBOK does not include the concept of a temporal dimension to knowledge and gives no guidance on how to phase the project according to the flow of knowledge. An expanded perspective on incomplete knowledge could provide a firmer theoretical foundation for this practice.

4.3. Importance of communication

Many studies place communication skills at the top, or near the top of the skills required by successful project managers [for example, see Ref. 11]. This can in part be explained by the existence of fuzziness in project parameters and outcomes. Many occurrences on projects are open to elastic interpretation and the consequences of this fuzziness can only managed by effective and persistent communication.

On a more formal basis, the theory of fuzzy sets can provide a calculus for handling fuzziness in project planning and should be included in an expanded perspective to incomplete knowledge.

5. Options approach to project planning

This paper so far, has presented the argument that the PMBOK risk management area is limited and should be expanded to incorporate other areas of incomplete knowledge. This section discusses the options approach to project planning. This approach systematically deals with incomplete knowledge and adds a temporal dimension that is lacking in the traditional approach. The options approach is promising but still immature and is included here to demonstrate the benefits to be gained by expanding the PMBOK.

In 1973, Black and Scholes [12] published their seminal work on the quantitative valuation of financial options. Financial options have become common investment vehicles in the financial markets, but it was Myers in 1977 [13] that first alluded to the analogy between financial-market discretionary investment and product-market discretionary investment (often called 'real options'). Myers drew the analogy that an investment project may be considered an 'option' on the produced commodity and the value of the 'options' generated by an investment are an important consideration.

The valuation of an option is portrayed in the next two diagrams. Fig. 3 shows the future value of an asset has a spread of value associated with uncertainty. A futures contract buys the *obligation* to take delivery of the asset in the future. The value of the futures contract is a depreciation of the expected future value. In contrast, an options contract buys the *right* (but not the obligation) to take delivery of the asset in the future. This eliminates the downside risk associated with the future value of the asset, but there is a premium to be paid for this benefit.

Fig. 4 shows two circumstances... high uncertainty and low uncertainty. Notice that the option value increases with increasing uncertainty. In planning terms, this means the attractiveness of retaining an option (flexibility) is high in circumstances of high uncertainty.

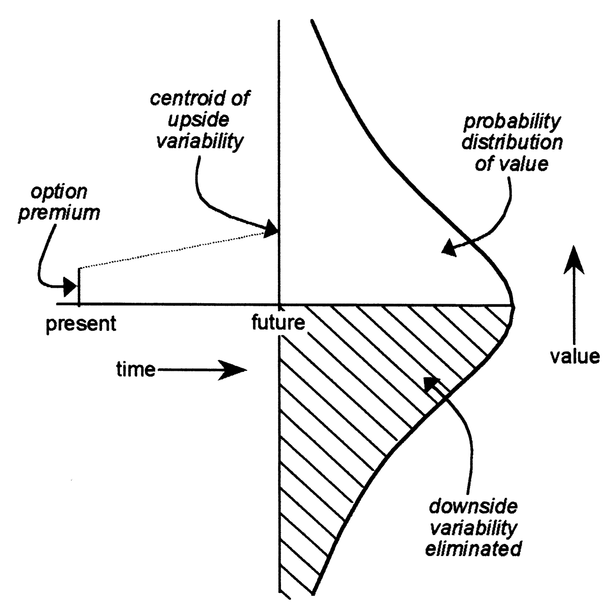

Fig. 3. Real options valuation.

[8] As an example of this practice, these multi-layer reserve budgets are formally allowed for under the Cost Schedule Control System Criteria.

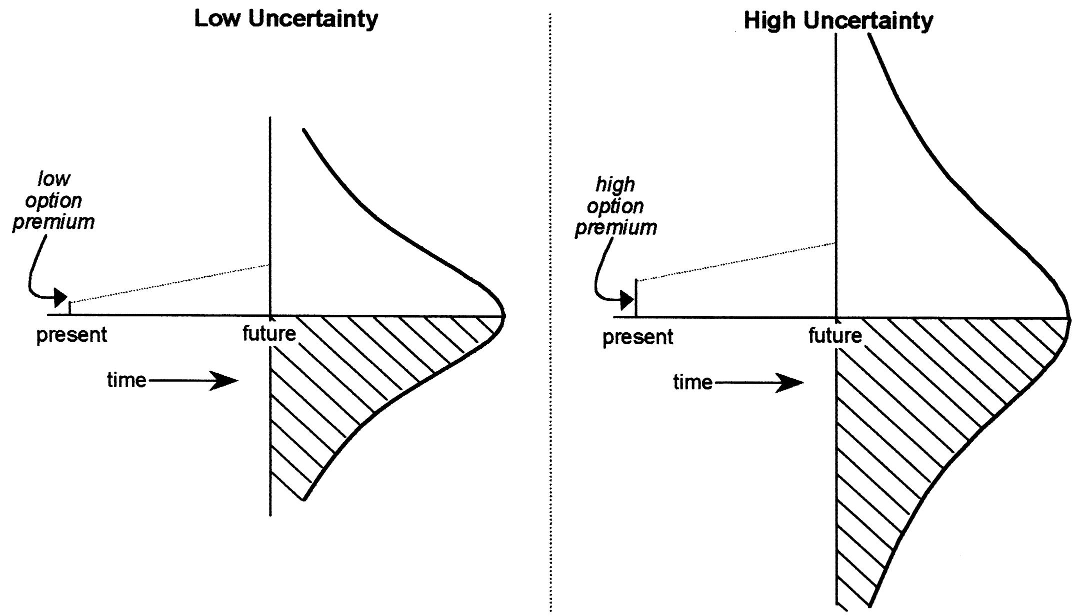

Fig. 4. High uncertainty = high options value.

How does this relate to project management? Overall, a project can be thought of as an option to use the asset it creates. For example, a project to modernise a production line buys the option (but not the obligation) to produce a new or revised range of products. The options approach considers the value of flexibility, not only the value of the project's net income stream.

At a detailed level, a project plan can be thought of as a nexus of options. The options approach considers the way flexibility is created and destroyed through time. Optimal project planning therefore maximises the total value of costs, income *and* flexibility.

As a project progresses, some decisions reduce flexibility and therefore reduce the options value. For example, when the design of the production line is committed, future project flexibility (and options value) is reduced.

Other decisions retain or increase flexibility and therefore increase options value. For example, securing additional floor space for the production line may increase downstream flexibility in the choice of machine tools.

The options approach recognises the 'value' and the cost of these options and encompasses this in the project planning and execution processes. In general:

- The greater the degree of flexibility afforded by a decision[9] or action, the greater the value to the project.
- The greater the degree of uncertainty that exists the greater the value of retaining or gaining flexibility.

If the options value is ignored, there will be a systematic under-valuation of some alternatives. All other things equal, this effectively distorts decisions to favour the safer, more predictable alternatives that are usually associated with a shorter time-horizon and limited perspective. Ultimately the result is a sub-optimal project management.

The options approach incorporates the concept of 'active management'. Unlike the probability-based approach, the options approach recognises the flow of knowledge throughout the life of a project. Experienced project managers know that projects require active hands-on management. Every day managers make decisions on alternatives, for example to proceed with or cancel work, to change the level of output, to reallocate resources and so forth. Indeed, prudent and efficient project management demands that these options be regularly assessed.

Trigeorgis [2] reviews the current state of research into real options. Table 1 below shows his categories of real options. All these categories are relevant to project management:

Kester [14] proposes the following scheme to assess the value of an option:

- *Step 1 Competitive advantage*. Is the option available to your organisation only or is it shared?
- *Step 2 Interrelations*. Is it a simple option or does it rely on other projects or activities?
- *Step 3 Urgency*. Will the option expire or be lost soon or can it be exercised in the future?

[9] Or indeed non-decision as there may be options value in deferring a decision until more information is available and the situation of uncertainty is reduced.

Table 1
Categories of real options [adapted from 2]

Category	Description	Important in
Option to defer	Holding a lease (or an option to buy) on valuable land or resources. The decision to build plant or develop a field can be deferred until justified by output prices.	Natural resource projects including real estate and farming.
Time to build option (staged investment)	Investment is staged such that the project may be abandoned if new information is unfavourable. Each stage is viewed as a compound option on the value of the subsequent phases.	R&D intensive industries and long-term development, capital intensive projects including construction, energy generation and start-up ventures.
Option to alter operating scale	If new market information is favourable production can be expanded. Conversely if new information is unfavourable production can be contracted.	Natural resource industries such as mining projects. Cyclical industries such as fashion, consumer goods and consumer real estate.
Option to abandon	Projects may be permanently abandoned to realise the resale value of the assets in second-hand markets.	Capital intensive industries such as airlines, railroads, financial services and new product markets in uncertain markets.
Option to switch (e.g. inputs or outputs)	According to new information, the output mix of a facility can be changed ('product' flexibility). Alternatively, the same output may be produced using different types of input ('process' flexibility).	*Product Flexibility*. Goods subject to volatile demand such as consumer electronics, toys and automobiles. *Process Flexibility*. All feedstock-dependant facilities such as oil, electric power, chemicals.
Growth options	Early investment such as R&D, undeveloped reserves etc. opens up future, interrelated growth opportunities such as new line of products, access to new markets and strengthening of core capabilities. (inter-project compound options).	All infrastructure or strategic projects especially high technology, R&D, multi-national operations, strategic acquisitions.
Multiple interacting options	A 'collection' of various options where the value of the whole is greater than the sum of the values of the individual options. It includes value-enhancing 'call' options, and downward-protection 'put' options.	Most real-world investment situations.

Let us examine a simple example of how project planning may use the options approach:

You are the Project Manager for the development of a new suburban site. Part of your project involves laying new power distribution cables. There is a related project to lay a new fibre-optic telecommunications infrastructure throughout the city. There could be major benefits if the same underground routes were used for both the power cables and the communications fibre. The problem is the fibre project has only just commenced.

Delaying the design of the power distribution system involves additional costs to your project. This produces a bias *for committing* to a design now. However, this will involve an irreversible cost if the design is unsuitable for the fibre network.

The uncertainty of design requirements for the fibre network means a high 'options' value associated with not committing to a design. This produces a bias *against committing* to a design for the power system.

In this example, let us assume the 'options' value of delaying the power system design, initially exceeds the 'real' costs involved with waiting.

At some later time in the project, knowledge about the fibre network will increase and uncertainty will decrease. The 'options' value will fall below the 'real' waiting costs and a decision to proceed design should be made. This decision point should be reflected in the project schedule.

Notice that the options approach has provided a systematic way of including uncertainty and the flow of knowledge in the project schedule.

The options approach could have been used to consider other hybrid alternatives. For example, if multiple power designs were produced in the absence of firm fibre requirements, the additional design cost may be offset by the options value of accelerated implementation once fibre requirements were firm. That is, by a current outlay you may purchase the opportunity (not the obligation) for future benefits.

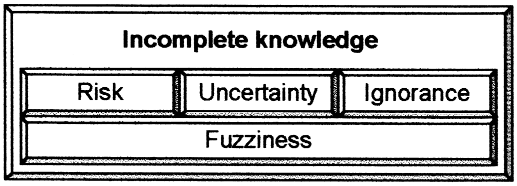

Fig. 5. The span of incomplete knowledge.

The value of real options is difficult to quantify and this has been acknowledged by Trigeorgis [2] who states the complexity of real investments is such that analytical solutions or numerical routines may not be available. Indeed, quantification may only occur when the probability distribution of future outcomes is known and as we have discussed this is not the norm for project management.[10] It is beyond the scope of this paper to discuss other techniques for valuing real options, but this does not detract from the demonstration that the options approach provides an important conceptual framework for project planning.

6. Conclusion

In conclusion, this paper has attempted to show that the PMBOK and other reference material is based on probability-based risk management theory. Analysis of the underlying assumptions of the probability-based approach shows it has limited applicability. A theoretically sound foundation for the management of imprecision would include fundamental uncertainty, ignorance and fuzziness as shown in Fig. 5 below.

The paper shows the expanded framework is better than the PMBOK at explaining certain aspects of observed project management practice. The paper also shows the expanded framework may lead-in new techniques for project planning and execution. An example is the real-options approach that looks promising, however more research is required on its practical application.

This paper does not advocate an immediate change to the PMBOK, but rather hopes to initiate discussion in the project-management fraternity about an expanded approach to managing incomplete knowledge. This should in turn prompt more research into practical applications that ultimately may find their way into the PMBOK.

[10] Where a futures market for the project's underlying asset is traded on a futures market (such as energy or primary production) options valuation may be meaningfully quantified.

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