Section Five

Creating and Valuing Flexibility in Systems Architecting

- Transforming Uncertainties into Opportunities Using Real Options Analysis

Flexibility is one of the strategies to ensure the value delivery of a System of Systems (SoS) during its life cycle in light of the changing external environment. This article discusses the notion of 'Real Options Thinking' to create flexibility and 'Real Options Valuation' to value flexibility when designing an SoS to manage significant uncertainties. We propose a 'Real Options Analysis' framework consisting of the dual parts of 'Real Options Thinking' (akin to good management intuition) and 'Real Options Valuation' (akin to stochastic optimisation) to promote a common 'options language', enrich vocabulary, sharpen our thinking and guide quantitative analysis when managing technical projects. Adopting 'Real Options Thinking' and 'Real Options Valuation' will increase our capacity to identify, create and secure both technical and managerial options through deliberate choice, in a cost-effective and timely manner. It will also increase our tolerance of uncertainties and empower us to actively manage uncertainties to create opportunities and reduce risks.

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1 INTRODUCTION – UNCERTAINTIES AS BOTH RISKS AND OPPORTUNITIES

In the context of Singapore defence, our real life complex systems are invariably Systems of Systems (SoS) which always operate in uncertain and dynamic environments. Typically, while systems architects design an SoS, programme managers develop an SoS that will operate in an uncertain and dynamic environment. The drivers of uncertainties can be both external and internal. External factors such as emergent threats, new operational concepts, disruptive technologies and shifts in supplier industry structure are largely beyond our control. On the other hand, internal factors come from uncertainties in the programme delivery and are generally well managed by current project management practices. The approaches and methods to deal with uncertainties arising from external factors are not well understood today. In addition, there is an increasing need to design and deliver SoS in fast-changing environments. Thus, it is essential to anticipate these known unknowns and, as far as possible, prepare for this class of uncertainties.

History shows that we are poor forecasters of exact trends. Over-confident forecasts like "640kb ought to be enough for anyone" from Bill Gates underestimated the uncertainty in demand and technology. Designing an SoS to specific trends may turn out to be costly as a single 'unknown unknown' can throw off our predictions and ability to react in the future. We would be better off predicting a range of scenarios and developing the feasible solution space containing all flexible on-demand responses that we can choose to adapt as new information becomes available with time, rather than designing our SoS to forecasted trends.

> *"Uncertainties are a source of risks and opportunities." - de Neufville, 2004*

Traditionally, for large-scale complex systems, uncertainties are treated as risks and are therefore undesirable. The approach towards uncertainties is consequently to manage them through risk mitigation. However, 'Real Options Thinking' introduces a paradigm shift in looking at uncertainties as sources of opportunities as well. This paradigm shift in thinking is essentially the act of capitalising on the opportunities embedded in uncertainties while limiting the extent of risks involved. This viewpoint is critical as most current engineering practices are conservative and may not exploit the potential upsides of uncertainty. We would be able to perform better if we can develop a dynamic strategy in anticipation of uncertainties arising from external factors. Through an SoS architecture that can evolve and adapt to a changing environment, we will increase our potential and ability to capitalise on emerging opportunities through uncertainties. Real Options Analysis is thus an Active Uncertainty Management technique as opposed to Passive Uncertainty Management techniques like risk management.

2 FLEXIBILITY IN SOS ARCHITECTING AS A STRATEGY TO ENSURE SOS VALUE DELIVERY

Systems architecting is an approach to design and build effective and efficient SoS. The SoS architecture *"provides the structure or skeleton of the system, as well as the principles, rules and guidelines governing the system design, creation and evolution. It also provides the broad framework, system level constraints as well as the relationship for the substructures and modules of the system. It determines the option available for future development."* (Tan,Yeoh, Pang & Sim, 2006). In order to preserve value over its life cycle, an SoS has to be able to handle dynamic complexity and a changing operational environment.

Flexibility is one of the key strategies to cope with environmental changes and dynamic complexity, and Real Options Analysis is one way to tangibly create and value flexibility in SoS. A working definition of 'flexibility' is as follows:

> *"Flexibility is the lifecycle property that allows a SoS to endure sets of changes with ease. It is an active and largely external approach to managing change." - adapted from Moses, 2003*

An SoS is flexible if we have the freedom to make our choices during life cycle operation to cope with the large external changes. Flexibility can be created and valued in systems architecting and designed using the Real Options Analysis framework.

Breakthrough engineering solutions have a common thread of incorporating flexible designs to cater to wide-ranging scenarios. These flexible designs are also known as 'options' and people have been practising 'real options thinking' even though the language of options may not be as ubiquitous. A good example is the flagship Underground Ammunition Facility (UAF) project, managed by DSTA, for high-density ammunition storage. DSTA has invested in the research and development (R&D) on protective infrastructure and related technologies for years to create options for MINDEF to address various defence needs. When the new challenge of creating new ammunition storage for the SAF arose in the face of tremendous pressure to free up land for national development, DSTA was ready to exercise the option and embark on the building of our first UAF. Apart from deriving direct value from the options created through R&D, this effort also generated emergent benefits by allowing DSTA specialists to set new safety standards, including obtaining the North Atlantic Treaty Organisation's acceptance and becoming a leader in the field.

3 DEFINING REAL OPTIONS

The science of options analysis began with financial options. A financial option gives one the right but not the obligation to buy an asset later at a pre-determined price. This means one can be better off during good times and have a fallback position during bad times. Should the value of the asset increase, one can profit from it. Should the value of the asset drop, one's losses are limited to the option premium. Black and Scholes (1973) developed the theory of pricing financial options while/and considering uncertainty, decision spaces and time in the equation. Option pricing has led to flexible financial structures, created a market of options transactions and reduced the volatility of the commodities.

A real option is the extension of the idea to value the flexibility of management decisions on a real or tangible asset. Asset owners need to know the price of their productive asset to determine its economic value. Since an asset can be put into creative use in multiple ways and the management has the flexibility to control how much resources to invest or withhold from it in the future, depending on the future demand - the value of the asset depends on their own possible courses of action. This viewpoint changed the perspective of asset valuation from historical cost valuation to prospective contingent valuation. The value is contingent on the future possible actions of the management. Today, real options analysis is being accepted as a conceptual and analytical tool to support strategic decision making under uncertainty by extending existing techniques of Net Present Value valuation. It is a bridging tool for strategic and financial decision makers.

It is important to distinguish an 'option' from our common understanding of it as an 'alternative' or a 'choice'. An 'option' is not another 'alternative' or 'choice'. Instead, it refers to our right, and not the obligation, to take an action (i.e. exercise it) at some point in time with an upfront cost. An option is a secured choice that makes it available on demand.

> *"A real option is a technical or management choice that we secure today at a pre-determined cost for a pre-determined time to have the right to exercise when needed without any obligation."*
> *- de Neufville, 2001*

A simple example of a real option in engineering design is the option to 'expand' (the action) in the design of the bridge across the Tagus River in Lisbon, Portugal. In the 1970s, the first bridge was designed for vehicular traffic when there was no demand for commuter railway system. However, the government insisted that the bridge structure be strong enough to carry rail traffic. Twenty years later, there were changes in technologies and in rail demand (pre-determined time to exercise options) and the government was able to exercise its option (option to expand) and extend rail service on the bridge. There was an upfront cost for this option - the bridge had to be reinforced when it was built (predetermined cost). However, when the environment changed in the 1990s, Portugal was able to take advantage of this opportunity to exercise the option that it had built into the technical design of the bridge 20 years earlier (Gesner & Jardim, 1998).

At face value, we may view such an example as simplistic. We caution readers to check against having any hindsight bias. We should reflect on the uncertainties and constraints that the decision makers would have faced in the context of their time. Additionally, the decision equation will be more complicated when there are several sources of uncertainty and only a few options for judgement.

4 REAL OPTIONS TYPES

A flexible SoS must have both technical and managerial options built into the architecture that can be exercised when needed. Both of these options are classified as 'Real Options' in our engineering SoS and are different from the Acquisition Options in procurement that we are more familiar with.

Technical Options are options that are created in the design of the technical SoS itself. Technical Options are called Real Options ***in*** SoS (de Neufville, 2002) as they are embedded in the technical design of the SoS architecture. Identifying technical options within the SoS would require a good understanding of the SoS and modular architecture. A classic technical option is the design of a dual operating mode. For example, straight stretches of roads can be designed and built so that we can use them as runways for aircraft. However, this means we have to design the roads with some limitations for transport use while ensuring heavier load requirements and removable barriers.

Managerial Options are options that are created to manage the process of SoS development and operation. They treat technology as a 'black box' and are essentially financial options taken on technical projects and SoS. Managerial options are the Real Options ***on*** SoS and are enabled by the technical options, contractual obligations of suppliers as well as financial and resource control over the process of SoS development and operations. Classic managerial options include options to defer a decision, alter the operating scale of the SoS or abandon some sub-initiatives. Back to the road-runway example, the management has the option to use roads as aircraft launch pads if enabled by built-in technical options.

Real Options allow the SoS to adapt to changing scenarios over time. This flexibility increases our ability to capitalise on upside opportunities and to limit our exposure to downside risks. Flexibility that is embedded in the technical design and management of SoS is important to improve the operational and technical effectiveness. The greater the uncertainty, the higher the value of each real option. Both technical and managerial options come at a cost known as the 'option premium'. The option premium can be seen in two ways: as the maximum price we should pay to have the managerial and technical flexibility, or as the price of our uncertainty. Certainly, we will not pay an option price that is higher than the cost of the uncertainty. When we have a bundle of options available across several review points in future, we can use a quantitative way to decide how much flexibility to incorporate into the SoS design and develop the roadmap of decisions.

Real options in SoS are thus an additional technique that can be used to value the flexibility of technical choices on SoS design. It is impossible to execute many of the management choices to expand capability or switch operating modes unless the initial design had the benefit of forethought. Securing technical options is costly and is subject to much inquiry because they will not be perceived as required, unless we measure the cost against the probable scenarios.

5 LANGUAGE OF REAL OPTIONS THINKING

Technical and managerial options can be broadly classified by whether they reduce downside exposure to risks, allow status quo or leverage upside opportunities, depending on how uncertainties evolve. If uncertainty was deemed to have a negative impact, exercising real options like the option to downsize or mothball would reduce exposure to risk. On the other hand, if the uncertainty turned out favourably, exercising real options that increase the exposure to these opportunities would reap a greater return. Table 1 groups some of the possible options (Trigeorgis, 2001) according to this classification. In the event where more information might change the course of action, the option to remain status quo might have to be deliberately created.

Function	Options	Description
Reduce risk exposure	Option to **downsize**	To alter operating scale and reduce capacity by removing features & resources.
	Option to **mothball**	To temporarily remove from active service & put into protective storage.
	Option to **terminate**	To stop and cut losses, typically when projects become unprofitable.
Status quo	Option to **defer**	To postpone starting or initiating an investment.
	Option to **continue**	To maintain status quo.
Leverage on opportunities	Option to **switch**	To move to an alternative mode of operation or design.
	Option to **expand**	To alter operating scale and expand capacity by adding features & resources.
	Option to **grow**	To invest in an option so it may open new options.
	Option to **restart**	To restart a temporarily closed operation.

Table 1: Types of Real Options

6 REAL OPTIONS EXAMPLES

Real Options Thinking can be applied in different scenarios of uncertainty. In the example of the bridge in Portugal, the uncertainty lies in the demand profile. The Portuguese government decided to create a real option which would become valuable if the demand for a commuter railway system indeed arose. This real option gave them the readiness to switch quickly, but there was naturally an option premium involved which included the cost of the extra load. Table 2 provides other case examples where real options can be applied and briefly illustrates the benefit and cost impact of these considerations.

No.	Uncertainty	Without Option	With Option	Example	Benefit	Cost (Option) Premium)	Option Type
1	Demand profile may change	Single equipment mode	Dual use of equipment	Roads as runways	Readiness to switch quickly	Operator training, cost of acquiring and operating both modes	Technical: Switch
2	Demand level is volatile	Right sizing	Spare equipment capacity	Extra network bandwidth	Handle small demand changes	Cost of under – utilisation and cost of spare capacity	Technical: Expand
3	Likelihood of failure of operating equipment	No redundancy	Redundant equipment as backup	Critical equipment for 24/7 readiness	Resilience and recovery	Original and backup cost	Technical: Switch
4	Technical feasibility; Demand	Go (high stakes) or No-go (forgo any potential)	R&D to investigate feasibility & gain subject knowledge	Defence R&D to explore new capability	Readiness to develop into project if feasible, or else exit with no further cost	R&D cost	Technical: Grow
5	Unknown user requirements and technical uncertainty	Waterfall development life cycle	Spiral development life cycle	Prototype development	Better risk management and customer satisfaction	Management cost is higher	Management: Expand, Downsize, Terminate, Continue
6	Future demand	Buy now	Lease with option to purchase later at lock-in price	Rent capacity with option to purchase later	Stop or continue at favourable price	Higher total cost	Management: Defer
7	Availability of new suppliers	Purchase reduced set now or all now	Purchase with option to buy more at lock in price	Buy x platforms with option to buy y more later if favourable	Fix the price today	Higher total cost than up front buy	Management: Continue, Expand
8	Different requirements from different users	Customised platforms	Standardise base platform	Multi-platform missiles, basic and modules software package	Mass customisation	Design cost for multiple interfaces	Management: Switch

Table 2: Examples of Real Options

7 CHARACTERISTICS AND APPLICATION OF REAL OPTIONS

Real Options has its pros (+) and cons (-).

+ Real Options enable the staging of decisions in roadmaps. We create flexibility by building in decision review points in the future and by defining the conditions under which they should be exercised. For example, an iterative development life cycle is superior to a waterfall life cycle when we explore new technical concepts. The deferred review points give the management the option to scale, hold or terminate the project based on the information feedback as uncertainty unfolds. It is the flexibility to stage the decisions that potentially creates more value than a waterfall approach. Similarly, a dual-purpose road is quickly used as a launch pad when an emergency need arises. Instead of formal timed reviews, the option to switch back and forth always exists during the life cycle of the project.

+ Real Options increase in value as uncertainty increases. The greater the uncertainty in a particular undertaking, the greater the need to have options, and the higher the corresponding value of the options we create. For example, the additional investment cost of extra capacity in a complex network will become viable once the uncertainty in the demand crosses a certain threshold.

– Real Options increase initial costs. Options add to the baseline configuration of the SoS and increase costs. Options are identified at the start of the project and hence, a higher initial upfront cost will need to be factored in to acquire the option at the 'option premium'. For example, suitable civilian transportation resources are requisitioned for military purposes when needed. However, there are certain administrative and periodic trial costs to ensure that the suppliers and equipment are ready for the activation. This option premium is the price we pay for the flexibility to manage the uncertainty.

In view of the essential characteristics of Real Options, we should realise that:

- ***Options are derived from the SoS.*** An option may be a logical or physical addition to the base SoS. This concept is a useful guide when we start to identify options and expand our option or solution space. For instance, a missile that must have multi-platform launching capability or customised software built upon a baseline module needs careful design of interfaces.

- ***Options are choices that are secured today.*** Unless we invest resources to secure the alternative that we may need later, it remains an unrealised possibility. This notion is pretty clear for technical options as they have to be incorporated in the initial design. However, this notion can be quite subtle for management options: a procurement option is 'purchased' today as an option premium so that we can choose to exercise it later at a pre-agreed price.

- ***Option investments have to be balanced.*** Options are secured at a price and we must invest in an economical portfolio that balances their benefits against their costs. This notion becomes apparent during front-end development when there are several sources of uncertainty with several types of option responses.

8 REAL OPTIONS ANALYSIS METHODOLOGY

This section walks through the major steps in realising flexibility in SoS. The Seven-Step Methodology for Systems Architecting shown in Figure 1 is an iterative and recursive process that moves from establishing systems architecting objectives to reviewing of the architecture. While flexibility is one of the requirements in painting the big picture, Real Options Thinking and Real Options Valuation will enhance the generation of solution space i.e. Build the Big Picture (Step 3) and Identify Capability Gaps (Step 4).

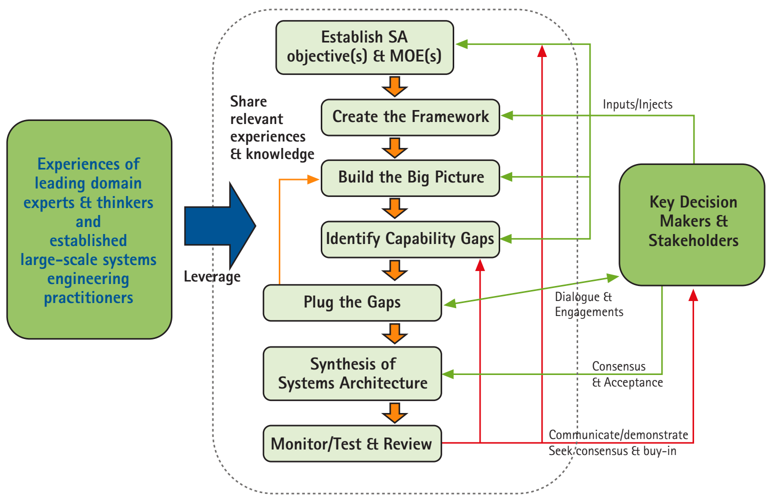

Figure 1: DSTA Seven-Step Methodology for Systems Architecting (Tan, Yeoh, Pang & Sim, 2006)

Figure 2 is our proposed Real Options Analysis Methodology which outlines the key steps in creating and valuing the real options. The joined Red circles are the scenarios at consecutive time stages (x-axis). The uncertainty of the future naturally increases over time. The small floating circles are the potential responses (i.e. decisions, secured choices or real options) that management and the technical team can take for each scenario. Both scenarios and responses are dependent on preceding choices and remind us of the legacy effect we may create.

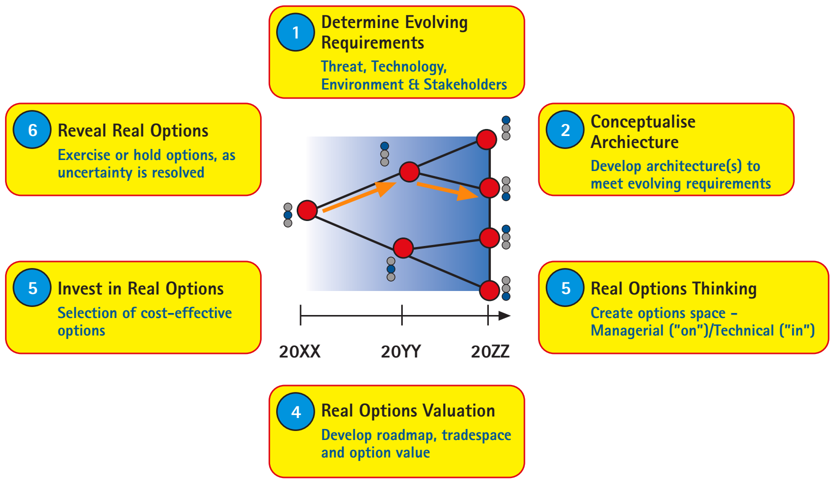

Figure 2: Real Options Analysis Methodology for Active Uncertainty Management

1) **Determine Evolving Requirements –** The focus of Step 1 of Real Options Analysis is to determine evolving requirements that can address uncertainties in the future. This requires a hard look at multi-time stages (e.g. in Figure 2, we illustrated it with three time stages onthe x-axis) and the probable scenarios at each time stage. We consider the technology capability today vis-à-vis projected uncertainties (i.e. known unknowns) coming from possible threat evolutions, key technology trends, changes in our operational concepts, operating environment and stakeholders.

2) **Conceptualise Architecture –** The art of systems architecting is a subject on its own. It is likely that there are several competing architectures proposed to meet the evolving requirements. Apart from functional needs, the systems architect has to trade off the various strategies for coping with dynamic complexity. This develops insights into the physical and non-physical aspects of the SoS, sources of changes and the dynamic behaviour of the SoS. The architectural descriptions should allow for a qualitative understanding and a quantitative inquiry for the valuation of options.

3) **Real Options Thinking to expand solution space –** Real Options present the most flexibility and value in areas of greatest uncertainties. After projecting where the biggest uncertainties lie (i.e. Step 1), we should explore the option/solution space and identify where real options can be created in the SoS. It is important to identify and clarify both managerial (i.e. Real Options on SoS) and technical options (i.e., Real Options in SoS).

4) **Real Options Valuation –** After identifying and creating the real option space, the real options are modelled by varying the designs and consequences. The steps are outlined in Figure 3. Specifically, there are two models to be developed - the Ops/SoS model and the Options Valuation model.

   a) ***Ops/SoS model –*** The Ops/SoS model is an Operational Analysis model that either produces a suitable response for a given threat scenario and/or generates the threat scenario that an SoS can handle given a specific set of constraints. It requires an operational and systems understanding of the specific engagement. At this level, a low resolution analytical or simulation model that transforms the key design inputs to measurable outputs is sufficient. We will use the Ops/SoS model to populate the response domain for the set of threat scenarios, and then proceed to compute the transition costs between sequential responses.

   b) ***Options Valuation model –*** Given the set of threat scenarios, responses and transition costs, we proceed to define a Measure of Effectiveness (MOE) for evaluating different roadmaps and possible constraints that preclude certain roadmaps. An optimisation model that considers the uncertainty and time will facilitate any combinatorial search. A point to highlight is that the solution is a recommendation of a suitable roadmap for the entire set of threat scenarios, and not just a response to a particular threat scenario.

   c) ***Roadmap –*** In practice, a first look at the roadmap is likely to trigger further inquiry and adjustments of both choices and input data. Once refined and stable, the roadmap is a guide for action. The roadmap chosen is the 'optimal' roadmap with the highest MOE score that satisfies the given constraints. It is important to note again that the roadmap is not a single path but a set of possible paths.

   d) ***Tradespace –*** The tradespace plots the evolution of the optimal roadmap against its cost and effectiveness. We can compare other roadmaps that are heuristically chosen to understand the differences.

   e) ***Option Value –*** The roadmap is derived from a probability tree. The MOE of a roadmap is an average value based on the responses for the given scenario. To have a good understanding of the variability of the MOE, we plot its probability distribution. We can then compare it with any other heuristically derived roadmaps. The difference will correspond to the value of the options that we have built in.

5) **Invest in Real Options –** The management is presented with the results, starting with the roadmap for the responses to the set of postulated scenarios. They will have to decide which real options to invest in, in order to secure the right to respond in the future. In practice, the roadmap will trigger additional questions on new options to be built today so that we can secure the future we want. It would likely be necessary to go back to earlier stages to reiterate the process.

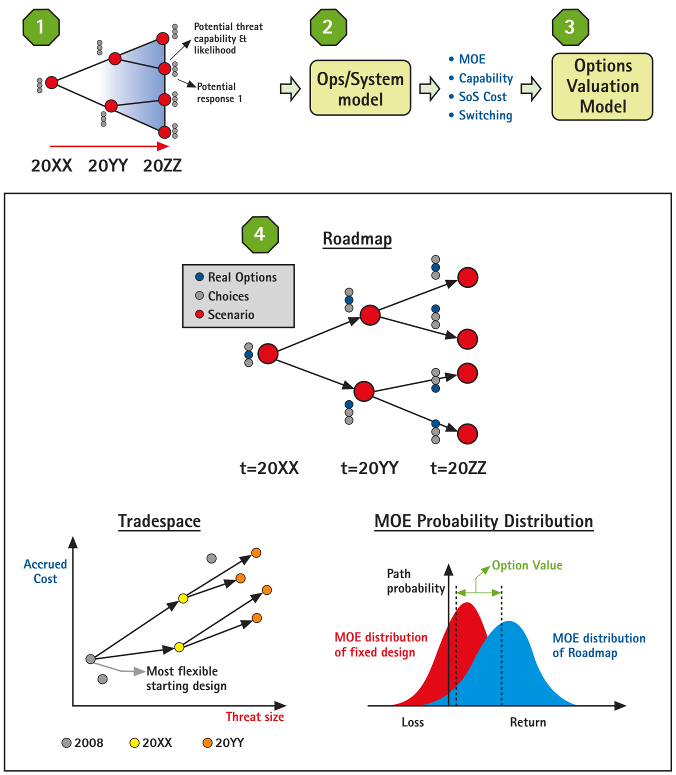

Figure 3: Real Options Valuation Process

6) **Review Real Options –** During operations, we will review if the real options invested earlier need to be exercised or deferred. If real options were built into the SoS, the management can and does have the right to exercise the options when the situation calls for it. Exercising the correct real options can only be done after re-evaluating their current benefits, and reassessing their impact as more information is revealed with time. The perceived value of each real option will become higher or lower over time as more information is revealed and uncertainty decreases. We have to keep reassessing the benefits and impact of each option at major decision points in order to decide which options should be exercised.

9 CONCLUSION

We will continue to design and build large-scale and complex SoS to face a future that is uncertain. By leveraging the input from past programme experiences and subject matter experts, we can broadly map out possible future scenarios. Uncertainty creates both risks and opportunities and our SoS has to remain flexible so that we can exercise the choices we want in response to future changes. We need to build real options into our technical engineering SoS that will enable such secured choices on demand. Real options are both technical and managerial in nature. While technical options are pre-built into the SoS upfront, managerial options give us the mandate to execute the real options with time, but without obligation.

A fresh perspective on flexibility is enhanced by Real Options Thinking and Real Options Valuation. Real Options Thinking is akin to good management intuition and gives focus by listing the canonical management choices and facilitating the identification and creation of real options. Real Options Valuation is akin to stochastic optimisation which helps us to compute the maximum economic price that we should pay for the uncertainty and recommend a roadmap that triggers further thinking. Together, we call this the Real Options Analysis framework. Adopting Real Options Thinking and Real Options Valuation will increase our capacity to identify, create and secure both technical and managerial options through deliberate choices in a cost-effective and timely manner.

We hope to promote a common 'options language', enrich vocabulary, sharpen thinking and guide quantitative analysis when managing technical projects. Having options will always be useful especially if they spread over space and time and both the management and the project management team can exercise them under appropriate circumstances. Flexibility is a critical consideration that will enable us to deal with uncertainty through Active Uncertainty Management. It is active because we would be engaged in exploring the real options that can be designed into the SoS. As real options are designed to be exercised in the future, we would also need to think about when these options should be exercised. It is a dynamic strategic planning exercise with the aim of securing the future, whichever way it turns out to be. It is also a strategic decision making tool for SoS architects, the management and project management teams.

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