Capability Development Framework for Defence Technology Investments

ABSTRACT

Strategic management literature has recognised the instrumental roles of the market's external requirements and the firm's internal capabilities in driving innovation.

Capability development has been identified as a key objective of defence technology investments. This article presents a framework that maps this capability development process to real options. The real options embedded in defence technology investments evolve as uncertainty decreases with technological maturity, and as the readiness for field transitions increases with clearer technological applications. Historical examples of important defence technological innovation and contemporary examples of technological innovation by DSTA are cited to illustrate the framework. The article concludes with a discussion on framing the capabilities as real options.

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INTRODUCTION

There has been extensive research conducted to understand the dynamics of technological development. Strategic management literature suggests that innovation can be driven by external requirements of the market (Schmookler, 1966), and by the activities and internal capabilities of firms (Dosi, 1982). Hence, besides technological development, the creation of capabilities is crucial in a technology investment (Clarke and Pitt, 1996; Helfat, 1994; Cohen and Levinthal, 1989). In defence technology investments, the development of indigenous defence technological capabilities is a strategic objective (Ang and Chai, 2009). This article builds on these discussions and presents a capability development framework for defence technology investments. Specific capabilities driven by application can be framed as technological options (Mitchell and Hamilton, 1988), while more broad-based options can be framed as a generic set of resources creating platforms for future developments and opportunities (Kogut and Kulatilaka, 1994; 2001).

LITERATURE REVIEW

Capability Development from Technology Investments

The multiple benefits from technology investments have been well discussed in strategic management literature. Practitioners such as Andrew and Sirkin (2007) recognise the indirect benefits of innovation such as knowledge acquisition. Knowledge and innovation are cumulative and evolutionary (Nelson and Winter, 1982). Thus, technology investments enable firms to come up with incremental innovations, which eventually culminate in the creation of technological variation or the quick adoption of technological changes. This allows the firm to move in tandem with the unpredictable technological discontinuities which punctuate the technological life cycle of any system (Tushman and Anderson, 1986). Besides developing particular technologies to meet expected market applications in the foreseeable future, technology investments also serve to develop firm-specific capabilities (Helfat, 1994) and the means to sustain competitive advantage for unpredictable long-term requirements (Clarke and Pitt, 1996; Cohen and Levinthal, 1989; Kogut and Kulatilaka, 2001). For example, technological capability reflects a firm's strength in discovery and innovation, and enables it to value, assimilate and exploit new knowledge (Cohen and Levinthal, 1989). The evolution of capabilities can be modelled by a life cycle involving the stages of founding, development and maturity (Helfat and Peteraf, 2003). In particular, a strategic objective of defence technology investments is the development of indigenous defence technological capabilities (Ang and Chai, 2007), while the R&D process can be framed as a capability development process (Ang and Chai, 2009).

Capability Transformation Process

R&D can be viewed as a process of resource transformation (Schmidt and Freeland, 1992) where firms create strategic options by transforming resources into capabilities which offer strategic flexibility. This capability development process can be modelled as a capability life cycle (Helfat and Peteraf, 2003). Ang and Chai (2009) propose that the capabilities developed in defence R&D evolve and can be categorised into technology maturity levels as follows:

Developmental Capabilities. These capabilities are required to develop technology applications for operational requirements such as enhancing operational capabilities to improve a weapon system. Using the Technology Readiness Level (TRL) framework developed by the National Aeronautics and Space Administration (NASA), developmental capabilities would correspond to TRL 7 and above. Table 1 illustrates this.

Technological Capabilities. These are vanilla options created from investment in technological capabilities. They offer the end user technological options i.e. the right but not the obligation to develop the technological capability into a system capability. These capabilities would be of TRL 5 and 6. These technological options correspond to the real options in strategic positioning proposed by Mitchell and Hamilton (1988). An example is the exploratory development in specific technologies.

Knowledge of the Firm. This refers to the compound options created from investment in knowledge of the firm. An example is investment in human capital. The knowledge created can be considered as owning a portfolio of options or platforms for future developments (Kogut and Zander, 1992). This would correspond to TRL 4 and below.

Technology Readiness Level (TRL)	
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and 'flight qualified' through test and demonstration (ground or space)
9	Actual system 'flight proven' through successful mission operations

Table 1. TRL in NASA

Transformation Map

In defence technology investments, the large-scale mission-oriented projects aim to develop specific technologies under conditions of high appropriability and high cumulativeness at the firm level (Malerba, 2004). These lead to a Schumpeter Mark II Model of innovation regime (Breschi, Malerba and Orsenigo, 2000) characterised by "creative accumulation" and the importance of experience gained from innovation efforts. Noting that the R&D process involves the development of capabilities which could be modelled as a capability life cycle (Helfat and Peteraf, 2003), Ang and Chai (2009) proposed a transformation map for this capability development in defence technology investments (see Figure 1).

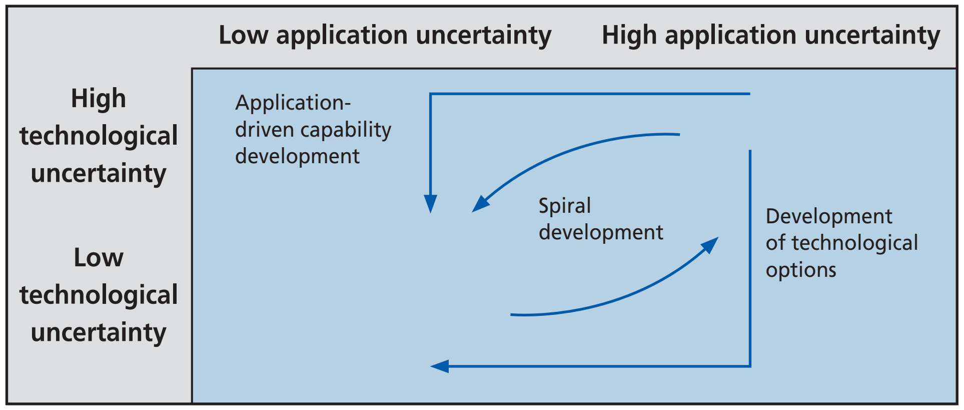

Figure 1. Transformation map of capabilities

The transformation could be seen as a development vector describing the maturation of the technology and also the resolution of uncertainty in the application. Different driving forces behind the capability development would lead to the development vector taking different paths. Thus, the real option embedded in a technology development programme would evolve accordingly. Within this framework, one can examine the relationship among defence technology investments, capability development and options creation for the uncertain future. The framing of defence technology investments as real options in capability development underscores the theoretical foundation for the application of real option theory to model defence technology investments.

The subsequent sections of the article illustrate this framework with historical examples of important defence technological innovation and contemporary examples of technological innovation by DSTA.

CASE STUDIES: HISTORICAL EXAMPLES

Data Selection and Analysis

The data selected are the capability development processes leading to some of the most important defence technological innovations (van Creveld, 1991; Perry, 2004). The capability development process for each innovation is analysed and mapped onto the transformation framework.

Submarines

Naval warfare has traditionally been waged through caravels, galleons, men-of-war and frigates on the water surface. The capability development for a submarine to attack a surface vessel from underwater was driven primarily by military application. The first workable submarine, the Turtle, was designed by David Bushnell in 1776. It was propelled by a hand-crafted screw and had room for only one crewman. This crewman had to drive a drill bit into the bottom of the hull of the target vessel, attach a waterproof time bomb and then escape before the bomb was detonated by a clockwork fuse.

The Nautilus was designed by Robert Fulton. During successful demonstrations in 1801 and 1805, it was able to cruise under the intended victim and tow the explosive bomb until the bomb came in contact with the target and detonated with a contact fuse. This craft had a copper-sheathed hull and it was equipped with a mast, bowsprit and two sails for surface propulsion and two hand-cranked screws to travel underwater (see Figure 2). Depth was estimated using a barometer, while air was supplied to the four-man crew by flasks of compressed air on board.

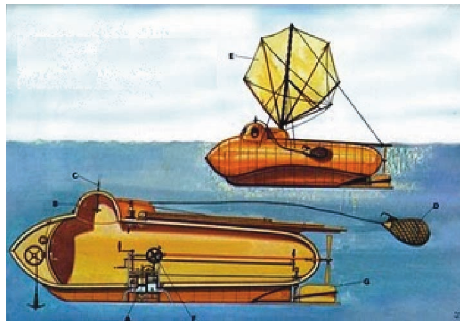

Figure 2. Artist's impression of Nautilus towing explosive bomb (Source: War and Game)

In 1900, John Holland won a submarine design competition held by the US Navy and went on to design the USS Holland (SS-1), the first practical combat submarine. It included innovative features such as self-propelled torpedoes fired from a reloadable tube, a battery-powered electric motor for submerged operations, and an advanced hull shape to allow it to move efficiently through the seas. Several innovations in military submarines were made in the period before World War One (WWI) – these included the development of diesel engines, improvement in periscopes and torpedoes, as well as the advancement of wireless technology which enabled submarines to be directed from shore bases. The transformation map in Figure 3 illustrates the application-driven capability development of submarines.

	Low application uncertainty	High application uncertainty
High technological uncertainty	Driven by military application, the capability of the submarine improved from the first workable submarine, the Turtle. An improved submarine, H.L. Hunley, sank a target in battle successfully.	Traditional naval warfare occurs on the water surface.
Low technological uncertainty	The first practical combat submarine was produced, introducing innovations such as the diesel engines, improved periscopes and torpedoes, and wireless technology.	

Figure 3. Transformation map: Application-driven capability development of submarines

Rockets

The Chinese were early users of gunpowder and invented gunpowder-propelled rockets in the early 13th century. Many subsequent military thinkers and technicians dreamt of giant rockets that could be launched to hit targets hundreds of miles away. However, the gunpowder propulsion was insufficient to propel a heavy rocket over any significant distance. In addition, the rocket could not be launched beyond the earth's atmosphere as the gunpowder would have no oxygen to burn for its propulsion.

Robert Goddard demonstrated in 1919 that these problems could be overcome by a rocket carrying its own oxygen supply in liquid form, combined with a fuel that had a very high and powerful burn rate, such as hydrogen.

Goddard's work inspired a group of German rocket enthusiasts to adopt his technical ideas for their own rocket experiments. In 1935, this group of rocket enthusiasts was enlisted by the German army to develop long-range ballistic rockets capable of carrying large explosive warheads. During World War Two (WWII), the group developed the V-2 rockets which produced 28,000kg of thrust. A fuel of liquid oxygen and alcohol together with a set of gyroscopes and flight guidance fins could launch a 400lb warhead of high explosives towards a target hundreds of miles away. Figure 4 shows the transformation map of the application-driven capability development of rockets.

	Low application uncertainty	High application uncertainty
High technological uncertainty	The Chinese invented rockets propelled by gunpowder. However, giant rockets could not be launched to hit targets a significant distance away due to insufficient gunpowder propulsion.	Invention of gunpowder
Low technological uncertainty	Goddard demonstrated rocket propulsion using liquid fuel. His technical ideas were further developed by the Germans who went on to build the V-2 rockets during WWII.	

Figure 4. Transformation map: Application-driven capability development of rockets

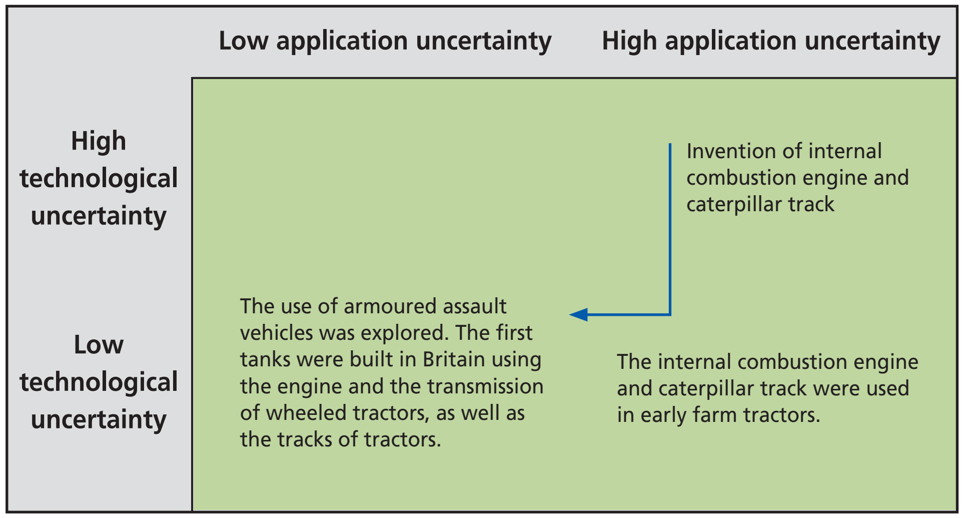

Figure 5. Transformation map: Development of technical options for tanks

Tanks

The key enabling technologies for the tank – internal combustion engine and caterpillar track – were mature technologies used in early farm tractors before the military innovation of tanks during WWI. During the war, opposing armies reached a deadlock as the traditional infantry attacks had become challenging due to increasingly effective firepower, as well as the extensive deployment of entrenchment and barbed wire for defence. Consequently, the use of armoured assault vehicles was explored as they could crush the barbed wires and protect against machine gun fire while approaching enemy trenches.

The first experimental tank was built in Britain in September 1915 using the engine and the transmission of wheeled tractors as well as the tracks of Bullock tractors procured from the US. An improved design with a much longer track was developed to enable the tanks to cross obstacles such as trenches which were up to 1.5m in width and parapets which were up to 1.4m in height. This was completed and demonstrated successfully in February 1916, and the War Office ordered 150 similar vehicles. On 15 September 1916, the 49 tanks available were sent on the first ever tank action to help the infantry assault enemy trenches on the Somme. The transformation map in Figure 5 illustrates the development of technological options that led to the military innovation of tanks.

Radar

In 1934, Robert Watson-Watt of the National Physical Laboratory informed the British Air Ministry that an aircraft could be detected at long range by radar waves. On the cathode ray tube (CRT) screen which had been commercially available since 1922, the aircraft could be displayed showing three key parameters: its position (coordinates), altitude and course plotted.

The reflection of radio waves from a metallic object was first demonstrated in 1855 and the ionosphere discovered in the early 1920s provided the essential pre-requisites for the development of radar. Using the principle that solid objects reflect radio waves, sending radio waves out on a fixed wavelength and recording the echo made it possible to calculate the range and direction of the object's movements. In February 1935, Watson-Watt demonstrated the detection of an aircraft flying at 10,000ft over a range of 13km.

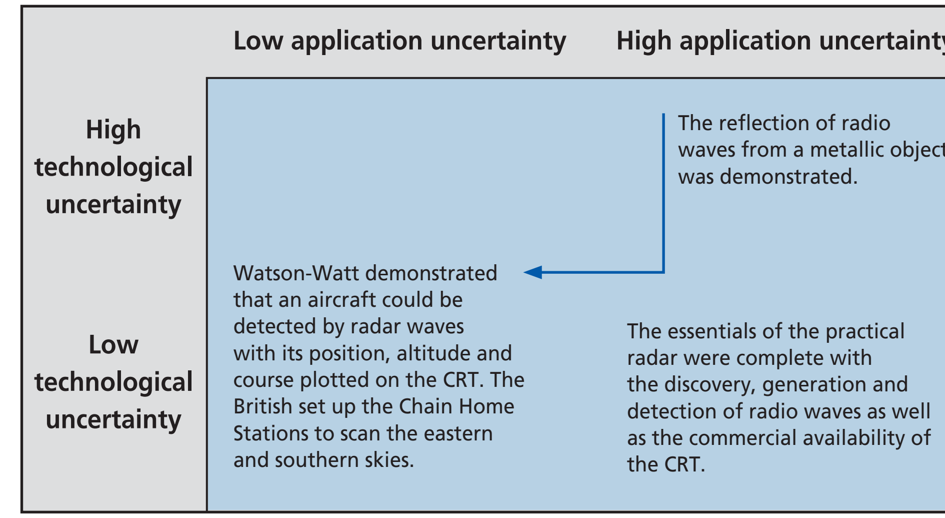

Figure 6. Transformation map: Development of technical options for radar
(Note: Radar does not generally depend on reflection from the ionsphere, but the ionsphere was the first object detected by radar)

By 1938, the British Chain Home Stations set up to scan the eastern and southern skies were reaching out with 60% reliability to 70 miles at 20,000ft. A chain of radar stations was built along the South and East coasts of Britain by 1939. Linked to a highly efficient control network, this early radar system played a crucial part in detecting formations of enemy aircraft as they approached the coast. As the Fighter Command was allowed to deploy its resources most effectively, the success of the Battle of Britain was secured. Figure 6 shows the development of technological options that led to the innovation of radar systems.

Military Aircraft

After the Wright brothers demonstrated the first heavier-than-air powered flying machine controlled by an on-board pilot on 17 December 1903, the more advanced military powers including the US and UK were not keen to develop aircraft for the next three years. Nonetheless, the enthusiasts experimented with dropping bombs, installing machine guns as well as mounting aerial photography equipment, and demonstrated many modern functions of air power. Although the aircraft only had primitive capabilities, the Italians used them in the 1911 war against the Turks in Libya to observe ground activity.

Many lessons were learnt – observers were needed to take notes of ground activity, and more pilots and aircraft had to be available. These in turn required a better servicing organisation. Better maps were also needed, leading to the development of aerial photography. Thus, the Libyan campaign taught the Italians the usefulness, rapidity and reliability of air reconnaissance, as well as the need for accuracy in bombing, the dangers of ground fire, and the limitations of equipment.

With the deadlock experienced during WWI, reconnaissance aircraft were the only means of gaining information on the position of enemy artillery and reserves. Fighter aircraft naturally evolved as a means of denying the enemy this invaluable information by arming aircraft to bring down other planes. However, early gunnery was primitive and the pilots were armed only with pistols and hand grenades. A suitable aerial weapon would be a forward-firing machine gun, but the bullets would hit the propeller blades as the gun was sited parallel to the aircraft fuselage.

Early experiments tried to overcome this problem by fitting deflectors onto the propeller blades to deflect any bullets that hit the propeller blades away from the pilot.

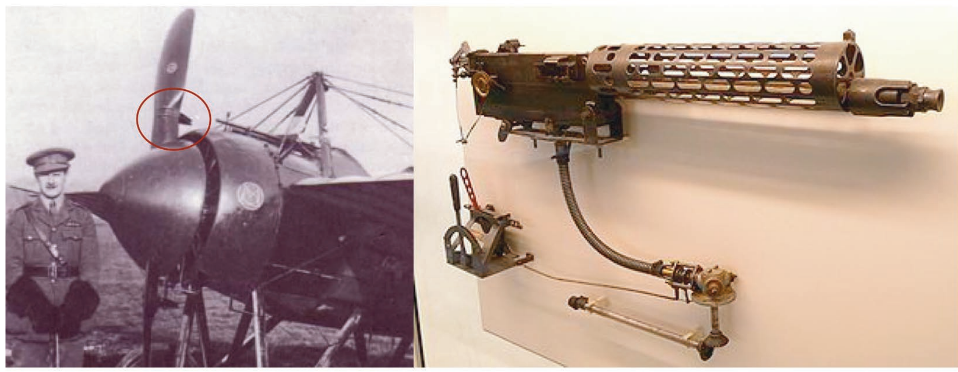

Figure 7. Deflector on propeller blades and a machine gun fitted with an interrupter gear (Source: Fiddlers Green)

Although successful, this method impaired aiming and many shots were wasted as the machine gun often fired into the deflector rather than through the propeller blades. The Germans solved the problem eventually with a proper interrupter gear that enabled the pilot to fire fixed guns at random through the propeller arc (see Figure 7). This mechanism was incorporated in the Fokker Eindecker 1 Fighter Aircraft by the summer of 1915 and effectively tilted the air warfare in favour of Germany, until the Allies' aircraft were similarly equipped with an effective interrupter gear in mid-1916.

An equally significant development was the advent of the bomber aircraft and the surge in demand for its bombing function. The first bombing raid of the war was carried out by French Voisin bombers on 14 August 1914 against German Zeppelin sheds near Metz. Typical of the early bombers, the Voisin was basically a general purpose aircraft from which up to 124lb of bombs could be dropped by hand. Hence, the development priorities for bomber aircraft were greater power and speed to improve on range and payload, as well as accurate navigation and bombsights. Midway through the war, the Italians developed the large Caproni Ca series which had a ceiling of 13,400ft in its later versions. It was also capable of speeds up to 85mph and bomb loads of up to 1,000lb. The Italians became the first to carry out true strategic bombing, amassing large numbers of aircraft to strike against a single target. The spiral development of bomber aircraft is illustrated in the transformation map in Figure 8.

	Low application uncertainty	High application uncertainty
High technological uncertainty	Spiral 2: Development of fighter aircraft was initiated as a means to bring down other aircraft. Bomber aircraft development was initiated and the concept of strategic bombing advanced.	Spiral 1: Enthusiasts experimented and demonstrated many modern functions of air power. The training of pilots and manufacturing of aircraft were primitive.
Low technological uncertainty	Spiral 2: The technical problem of mounting machine guns on fighter aircraft was solved with the interrupter device. Specialised bomber aircraft were produced.	Spiral 1: The Italians took the primitive aircraft to war in 1911 with the main task of observing ground activity, and they learnt important lessons.

Figure 8. Transformation map: Spiral development for bomber aircraft

CASE STUDIES: CONTEMPORARY EXAMPLES

Underground Ammunition Facility

The limited land resources for ammunition storage facilities resulted in the construction of the Underground Ammunition Facility (UAF) for the Singapore Armed Forces (SAF). There was no precedent of a large-scale underground ammunition facility developed within a densely populated and urbanised area. Thus, significant technology investments were required to meet the protective infrastructure requirements and develop the related technologies, which could be harvested as feasible options to ensure explosion containment. The knowledge gained from the successful technology development and application in the construction of the underground cavern paved the way for the construction of underground caverns of similar scales. This knowledge was used to set new safety standards and contributed to the North Atlantic Treaty Organisation safety codes. In addition, the suite of technologies developed and applied for the UAF could possibly be adapted for other uses, such as using underground caverns to store crude oil and attendant oil products. The transformation map in Figure 9 shows the application-driven capability development of the UAF.

Infrared Fever Scanner System

In response to the Severe Acute Respiratory Syndrome (SARS) crisis in 2003, there was an urgent requirement by the health authorities to identify individuals with body temperatures that were higher than average. The usual method of using thermometers to measure temperatures was tedious and time-consuming. This led to the opportunistic use of the mature infrared technology for the Infrared Fever Scanner System (IFSS) as shown in Figure 10.

Figure 10. IFSS

	Low application uncertainty	High application uncertainty
High technological uncertainty	Significant R&D investments in protective infrastructure and related technologies	No precedent of a large-scale underground ammunition facility developed within a densely populated and urbanised area
Low technological uncertainty	Capability for the construction of underground caverns for ammunition storage	

Figure 9. Transformation map: Application-driven capability development of the UAF

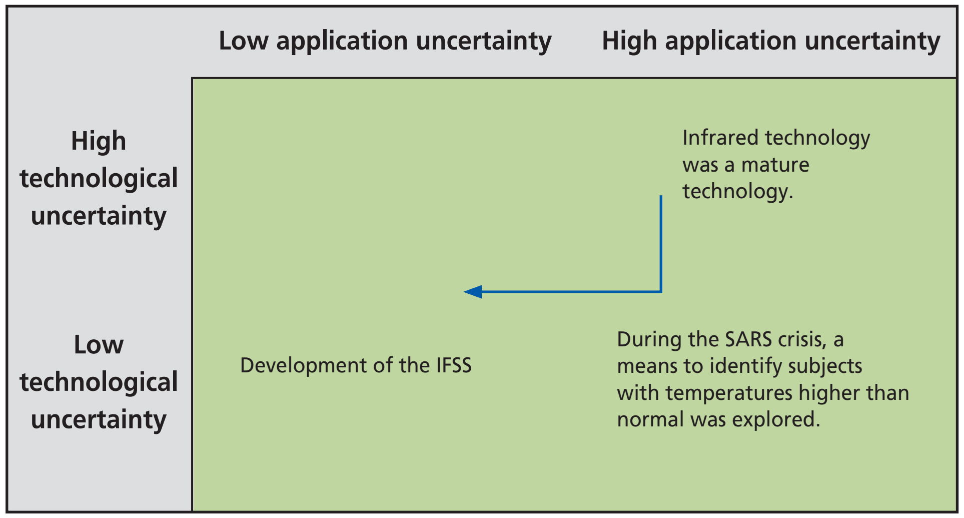

Figure 11. Transformation map: Development of technical options for IFSS

Due to the urgent requirement, the initial IFSS categorised the subject's temperature based on shades of colour as a proxy. This has since evolved to the numeric tagging of temperature to the subject's forehead as one appears on the sensor computer screen. The technology for numeric tagging was already well developed in other applications. The use of this technology provided better resolution and accuracy as compared to the use of colours as a proxy. The IFSS proved to be useful in the temperature filtering process to contain the spread of the H1N1 virus.

While the application of the infrared technology for temperature screening was opportune, it has not been proven that the infrared technology will be reliable under different operating conditions such as high traffic flow, dust, humidity and ambient temperature. More R&D and trials are required to ensure that the technology is sufficiently mature to be deployed for temperature screening under different operating conditions, with an acceptable false alarm rate. Figure 11 shows the development of technological options that led to the innovation of the IFSS.

Indigenous Unmanned Aerial Vehicle

R&D efforts to build up indigenous capability in Unmanned Aerial Vehicle (UAV) technology was initiated in the early 2000s. Initial efforts were focused on developing a man-portable mini-UAV called Skyblade I to support Army battalion operations. However, technical challenges were encountered as the subsystems had to be small and lightweight, yet robust and reliable. Extensive field trials and design revisions were carried out before Skyblade III progressed successfully from an R&D prototype to a production model. The product was a joint effort between DSO National Laboratories (DSO) and Singapore Technologies Aerospace, and it became the first indigenous UAV to be deployed by the SAF in 2009. The knowledge and experience gained from this R&D effort is now channelled into the development of a larger class of tactical UAV called Skyblade IV. The spiral development of the UAV is shown in Figure 12.

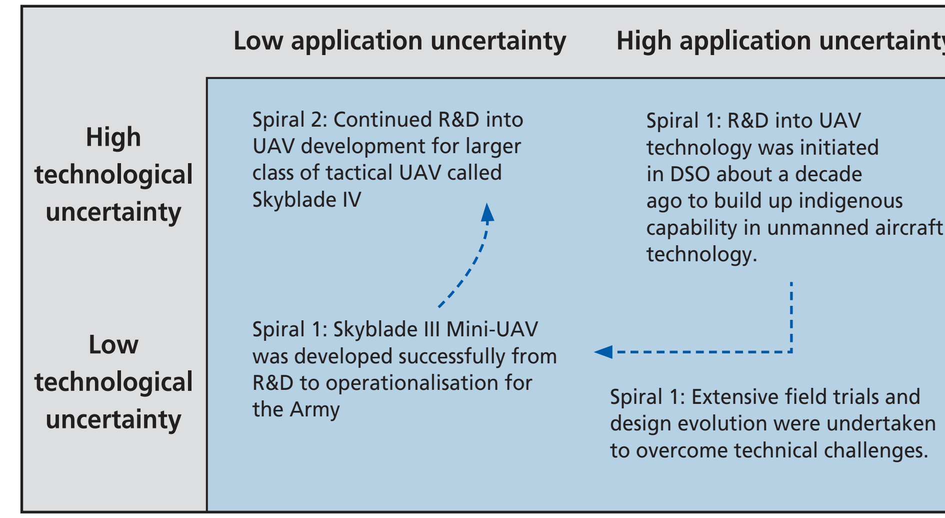

Figure 12. Transformation map: Spiral development of UAV

DISCUSSION

The case studies illustrate the transformation map framework which examines the relationships among defence technology investments, capability development and options creation for the uncertain future.

Capability Development Process

The capability development processes for submarines and rockets were driven by military application. On the other hand, the military innovations of the tank and radar were the result of application-driven development, where key enabling technologies were developed and matured independently beforehand. The capability development for military aircraft demonstrated a different process in which new applications and requirements for technological development were discovered through spiral experimentation and a learning process.

Capabilities as Real Options

Real options are investments in physical assets, human competence, and organisational capabilities that provide the opportunity to respond to future contingent events (Kogut and Kulatilaka, 2001). Since R&D investments are the technological equivalent of a financial options contract, technology investments with high levels of uncertainty are better assessed using real options (Mitchell and Hamilton, 1988). Such projects offer the investor the right but not the obligation to create a product at some point in the future, in return for a limited downside in investment. This is substantially useful during times of uncertainty.

Kogut and Kulatilaka (1994; 2001) argue that capabilities are real options as they form platforms that create a generic set of resources and represent investments in future opportunities. A heuristic framing of capabilities as real options was proposed to guide the normative evaluation of exploitation and exploration. Noting that technological options differ in strategic purposes and have different levels and types of uncertainty involved, MacMillan and McGrath (2002) propose that R&D projects should be treated as one of the three types of real options, depending on their degree of technical and market uncertainty:

a) Positioning options are taken out to preserve a company's opportunity to compete in future technological arenas that are still unclear.

	Low application uncertainty	High application uncertainty
High technological uncertainty	**Positioning options** "Modular innovation" e.g. quantum leap in weapon systems performance	**Stepping-stone options** "Radical innovation" e.g. R&D investments in emerging breakthrough technology which would influence the outcome of the war
Low technological uncertainty	**Enhancement and platform launches** "Incremental innovation" e.g. upgrading weapon systems	**Scouting options** "Application innovation" e.g. fielding existing technologies in new doctrines of operation

Table 2. Technological and scenario uncertainties in defence technology investments (Source: Modelled after MacMillan and McGrath, 2002)

b) Scouting options are used to learn about the market by probing or offering prototypes to potential early adopters.

c) Stepping-stone options are created when market and technological uncertainties are high to build both market insights and technical competence systematically.

Framing the R&D project as one of these three options will enable a company to progress without exposure to potentially catastrophic downside risks. In highly unpredictable situations, smart companies have learnt that the deployment of a portfolio of options is the best way to ensure their ability to respond effectively to future challenges.

Strategic Heuristic

In the particular case of defence technology investments, the portfolio would likely include projects with different levels of uncertainty in developing the technology and fielding the application (see Table 2). The level of uncertainty of a greenfield technology is high. Conversely, the level of technological uncertainty could be low if the enabling technologies have been developed and matured independently beforehand, sometimes outside a military laboratory. For example, the internal combustion engine and caterpillar track used in the innovation of tanks were mature technologies used in early farm tractors.

The innovation of tanks also illustrates the importance of certainty in fielding the application. While the caterpillar tractors had been used in military service, either as a means of hauling cargo or a device for pulling very large artillery pieces, few people thought of arming caterpillar tractors as there was no requirement before WWI. It was only after the deadlock situation at the trenches of the Western Front that armies realised the importance of fielding an armoured fighting vehicle.

The strategic purposes would likely vary for defence technological projects with different levels of uncertainty in developing the technology and in fielding the application. Defence technology investments in areas with high uncertainty in development and application may aim to create breakthroughs which would give an edge over adversaries. On the other hand, defence technology investments in mature technologies may aim to create incremental innovations in existing applications. Nonetheless, with creative accumulation in the evolution of technology, options embedded in a technology development programme evolve as (a) the technological uncertainty decreases with technological maturity, and as (b) the readiness for field transition increases with identification of applications.

CONCLUSION

A strategic objective of defence technology investments is the development of indigenous defence technological capabilities, while the R&D process can be viewed as a capability development process. This article illustrates the capability development framework proposed by Ang and Chai (2009) through historical examples of important defence technological innovation and contemporary examples of defence technological innovation by DSTA. This capability development framework contributes to the literature on the dynamics of technological strategy innovations. The strategic heuristic can be examined through the relationships among defence technology investments, capability development and options creation for the uncertain future. Specific capabilities driven by application can be framed as technological options, while more broad-based options can be framed as a generic set of resources creating platforms for future developments and opportunities.

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BIOGRAPHY

Ang Choon Keat is a Senior Engineer (Building and Infrastructure) and works on planning, designing and managing protective building and infrastructure developments. He is a registered Professional Engineer (Civil) in Singapore. Choon Keat was previously Manager (Plans) at the Defence Research and Technology Office where he was involved in the management of the Ministry of Defence Research and Technology portfolio. He graduated with a Master of Engineering (Civil Engineering) degree from Imperial College London, UK in 1999 under the DSTA Undergraduate Scholarship. He further obtained a Master of Science (Operations Research) degree from Columbia University, US in 2005 under the DSTA Postgraduate Scholarship. Choon Keat is currently pursuing a Doctor of Philosophy (Management of Technology) degree from the National University of Singapore.

Lee Keen Sing is a Principal Engineer (Land Systems) and leads a team in innovating technological solutions and modifying equipment in response to requirements of the Singapore Armed Forces (SAF). He is also a Senior Investment Manager of Cap Vista Pte Ltd which identifies and invests in companies that develop cutting-edge technologies to support Singapore's defence initiatives. He was previously involved in the areas of Systems Architecting, Capability Development and R&D. Keen Sing obtained a Master of Engineering (Mechanical and Production) degree from Nanyang Technological University (NTU) under the NTU Research Scholarship and the National Science and Technology Board Postgraduate Training Initiative scheme in 1999. Under the DSTA Postgraduate Scholarship, Keen Sing graduated with a Master of Science (Engineering and Management) degree from the Massachusetts Institute of Technology, US in 2004.

Ng Si Jing is an Analyst (DSTA Masterplanning and Systems Architecting). She examines how technology options may impact the effectiveness of SAF missions. She was involved in the local development of unmanned aerial vehicles. A recipient of the DSTA Undergraduate Scholarship, she graduated with a Bachelor of Science (Mechanical Engineering) degree from Cornell University, US in 2004 and a Master of Science (Aeronautics and Astronautics) degree from Stanford University, US in 2005.