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Chapter 25

Singapore's Defence-Industrial Ecosystem

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1. Introduction

Singapore's defence-industrial origins date back to independence from Britain in 1965. Although colonisation had acted to suppress the island state's economic transformation, it had also implanted strong positive forces that would project the country forward to construct a powerful defence economy. These forces included a functioning civil service, the rule of law and adoption of the English language. In a country where 90 per cent of the population are of Chinese ethnic origin, the primary language is English, not Mandarin. In the defence domain, however, Britain had left precious little in the way of capability as arms had always been sourced from the colonial power. On final departure in 1968, Britain's military forces left independent Singapore with no air force and navy, and just a meagre army comprised of mostly Malay forces. Withdrawal was also combined with the closure of Britain's huge military base on the island, leading to the loss of 40,000 local jobs and a fifth of Singapore's national income.[1] This dealt Singapore a destructive economic blow, and also left it facing a strategic calamity. This was because surrounding the country was an arc of Islamic states that was, and is, perceived as an existential threat to Singaporean sovereignty. Such fears in the early decades following independence were fuelled by anti-Chinese riots and killings in both Malaysia and Indonesia. Additionally, Singapore suffered insecurity from intermittent regional frictions, including fishing and maritime territorial disputes, 'water wars' with Malaysia and actual military conflict with Indonesian armed forces during the latter's aggressive *Konfrontasi* era. It is little wonder, therefore, that Singapore felt vulnerable, and sought to quickly develop indigenous military capability, including defence-industrial capacity.

Singapore's response to such threats was strengthened by the election of Singapore's first prime-minister, Lee Kuan Yew, who proved a strong and visionary leader. His view was that development must be defended, and resources were allocated for the build-up of Singapore's Armed Forces (SAF). A strategy of deterrence was crafted, whereby Singapore would be viewed by aggressors as a 'poisoned shrimp'; that is, notwithstanding the small size of the country,

potential combatants would be deterred from attacking due to unacceptable casualties and damage that a powerful SAF would inflict upon them: "easy to swallow but impossible to digest".[2] An appropriate strategy was devised to overcome demographic constraints that would emphasise transformative defence innovation through niche military-technological 'force multipliers'.[3] Civil-military fusion was the intended result via high value dual-use technology synergies. Technology is a critical component of Singapore's success story, but accommodating the process of accelerating and intensifying innovation is investment into human capital. The energy and creativity of Singaporean engineers and scientists is a significant consideration, influenced partially by the strategic imperatives derived by the country's small size, but also by a Chinese socio-economic cultural that embraces such traits as *Mianzi* (saving and creating face).[4]

Singapore's small country defence-industrial model has proved remarkably successful in catapulting the industry from a position of dependence some 50 years ago to the present status of industrial, competitive and innovational maturity. Singapore's underlying defence-industrial strength has expanded, *pari passu,* with growth in the breadth and depth of its commercial economy. Table 1 evidences Singapore's contemporary and comparative success as a defence economic power. As a small nation bereft of natural resources, and with a population of around just six million people, Singapore has constructed a powerful economy, sponsoring an impressive military budget and housing the world's 40th biggest defence-industrial company. These defence economic metrics cast all other major Southeast Asian neighbours into the shade and compare favourably with the performance of other small countries which have benefitted from a long history of industrial development and/or the possession of vast amounts of oil and energy resources.

Table 1: Singapore Comparative Defence Economic Performance, 2017

Country	MILEX (US$ billion) Current	GDP (US$ billion) Nominal	Population (million)	GDP per capita (US$) Nominal	MILEX/GDP (%)	Defence firms in top global 100
Singapore	10.1	324	5.6	55,236	3.3	1(40)
Southeast Asia						
Malaysia	3.5	315	31.6	9,945	1.1	0

Indonesia	7.9	1,016	264.0	3,847	0.8	0
Thailand	6.1	455	69.0	6,594	1.4	0
Vietnam	4.9	224	95.5	2,343	2.3	0
Brunei	0.3	12	0.43	28,290	2.9	0
Other Small States						
Kuwait	6.7	120	4.1	29,040	5.8	0
Norway	6.3	399	5.3	75,505	1.6	2(81 &95)
Oman	8.4	73	4.6	15,668	12.1	0
Qatar	3.4	166	2.3	71,991	N/A	0
Sweden	5.5	538	9.9	53,442	1.0	1(32)
Switzerland	4.6	679	8.4	80,190	0.7	1(73)

Source:SIPRI,2018Database(MILEX,MILEX/GDP), World Bank 2017 (Population, GDP, GDP Per Capita) *Defense News*, 2018 (top 100 companies)

By reference to Singapore's strategic and policy environment, the purpose of this chapter is to explore the development of the island state's defence-industrial base set against the broader defence economic context. Discussion begins with an overview of defence spending, procurement and defence-industrial development patterns. This is then followed by the articulation of a quadrilateral defence-industrial model that captures the principal influences affecting the development of Singapore's defence economy. Taking each in turn, the core components comprising strategic foresight, technological absorption capacity, exposure to trade and foreign partnerships and defence offset will be explained and analysed. The chapter closes by offering a brief prognosis on the future prospects of Singapore's defence industry.

2. Evolution of defence-industrial structures

Other than some basic in-country maintenance, repair and overhaul (MRO) provision for British and allied forces during WWII, Singapore possessed no defence-related manufacturing capacity until the late 1960s. The turning point was the election of Lee Kwan Yew and his determination that Independence would be defended, as far as was feasible by indigenous capability. Sovereignty would not be undermined by the capriciousness of foreign powers imposing arms embargoes when political considerations supersede strategic partnerships. It was inevitable, therefore, that defence industrialisation would be encouraged, but

from the outset local defence companies would not benefit from direct government subsidies.[5]

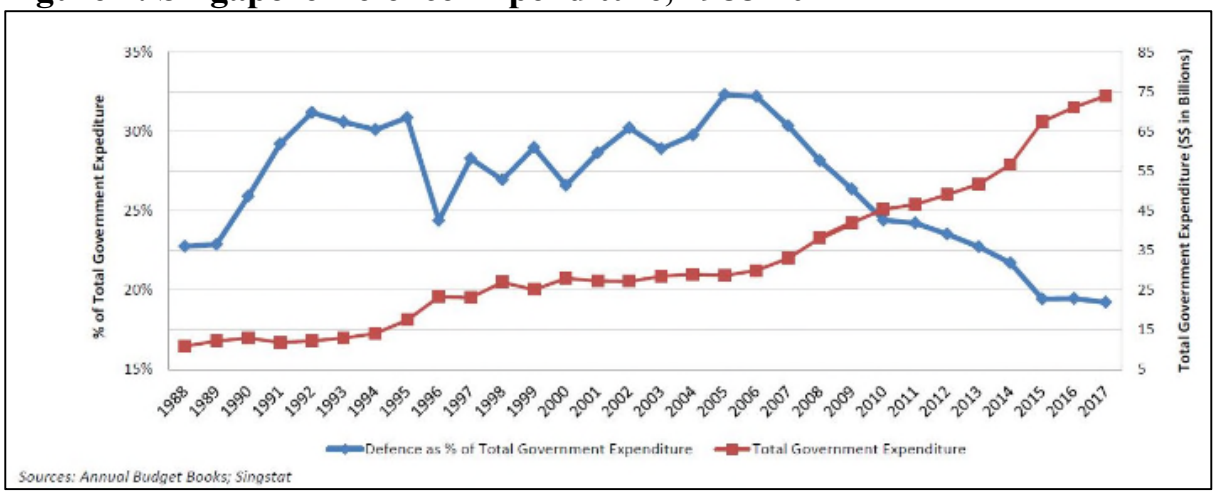
The defence-industrial development process began in 1967, with the establishment of Chartered Industries, the first of three divisions that would later (1989) become the state-owned Singapore Technology (ST) Corporation. Chartered Industries commenced production of several different types of ammunition and small arms, and gradually expanded capacity to include artillery shells and armour-piercing rounds for the AMX-13 tank's main gun. In 1976, CI purchased the rights of the SAR-80 assault rifle from Britain's Sterling Armament Company. The rifle was upgraded, and some 100,000 indigenously modified SAR-80s were produced for local and export use.[6] ST's second division was established in 1973, to locally design and produce mortars derived from a Finnish model. The division later produced the Israeli supplied M68 155mm howitzer, which was later locally modified and exported as the FH-88. Finally, in 1971, ST Automotive Engineering was launched to modify imported Mercedes heavy three-ton trucks to military spec standard. Foreign armoured personnel carriers, such as the US-supplied M-113, were additionally modified to serve as platforms for locally developed mortars and foreign supplied surface-to-air missile systems.

In 1974, the Singaporean government formed Sheng-Li Holdings to provide strategic oversight and management of the island state's rapidly expanding defence-industrial base. The policy focus was not only on land systems, but also the separate and rapidly evolving naval and aerospace entities. In the naval domain, Singapore Shipbuilding and Engineering was launched in 1968, and through overseas technology transfer agreements, quickly developed warship production. A major partnership was with West Germany's Lürssen Werft, leading to the license production in 1974-5 of TNC-45 missile-equipped gunboats that accommodated Israeli-produced Gabriel missiles. In 1989, the same German company provided the design and a prototype vessel for the local construction of five corvettes that integrated US Harpoon ship-to-ship missiles. Aerospace was serviced by the Singapore Aerospace Corporation. The company was created in 1981 for local assembly of Italian supplied SIAI-Marchetti S-211 trainer aircraft, and also the provision of MRO for numerous types of military aircraft, engines and avionics equipment, including refurbishment of the American supplied A-4S Skyhawk fighter and depot-level maintenance of C-130 transport aircraft.

In 1990, in a move to promote organisational synergies, Sheng-Li Holdings was restructured and renamed Singapore Technologies (ST) Holdings. The thrust of this restructuring was to commercialise operations, with ST in 1994 coming under the control of the State Investment Company, Temasek. Through mergers and acquisitions, ST rapidly developed a commercial portfolio that included telecommunications, financial services, tourism and transportation. Singapore's

defence industry was clustered into what was called ST Engineering (ST Engg), as part of a deliberate plan to diversify and cross-thread its functions into appropriate commercial activities across the expanding ST conglomerate. ST Engg became a publicly listed company, with Temasek Holdings owning a 51 per cent controlling share. ST Engg is presently structured into four major companies, namely - ST Aerospace, ST Marine, ST Electronics and ST Kinetics. The holding company has over the past five years derived most of its revenues and net profits from aerospace, followed by electronics, land systems and marine.[7] Significantly, ST Engg has evolved from a sole focus on the domestic market to operating as a global multinational defence company, with operations spread across the globe. In 2017, ST Engg employed 22,000 workers in 22 countries that generated S$6.62bn in revenue and S$511.9mn in profit.[8] The company is a success story, ranked 40th in the world's top 100 defence companies.

Figure 1: Singapore Defence Expenditure, 1988-2017



Source: Extracted from *Speech Transcript by Minister for Defence Dr Ng Eng Hen at the Ministry of Defence Committee of Supply Debate 2018*, Ministry of Defence, Singapore, 2 March 2018, at: https://www.mindef.gov.sg/web/portal/mindef/news-and-events/latest-releases/article-detail/2018/march/02mar18_speech1 (accessed on 16 September 2018). Data are shown in current prices.

2. Procurement profile

Notwithstanding defence funding pressures, ST Engg has embarked on an ambitious post-2030 'Road Map' for a manpower-lean military capability aimed at doing more with less.[9] Detailed analysis of programme costs is not possible because Singapore's defence acquisition spending is secret, and thus the figures have never entered the public domain. It is clear, though, that the continuous and costly procurement of 'big ticket' platforms from foreign vendors, with whom ST

Engg plays an important collaborative role, is a major undertaking. Aside from contributing to various programmes across land, air and naval systems domains through partnerships with foreign vendors, ST Engg has assumed the prime contractor role for major locally developed platforms. These include the Next-Generation Armoured Fighting Vehicle that will be an upgraded - more capable - version of ST Kinetics Bionix infantry fighting vehicle;[10] and there is a possibility of a local build for, firstly, the navy's Multi-Role Combat Vessel (MRCV), slated to replace the venerable (in-service since the late 1980s) *Victory*-class missile corvettes, and, secondly, the planned Joint Multi-Mission Ship (JMMS) that will offer larger and improved aviation capacity compared to the locally-built *Endurance*-class landing platforms dock vessels. The procurement process for these vessels will likely follow the conventional model of the lead ship being built in a foreign yard, with remaining units produced domestically under licence. Singapore's major arms procurements since 1980 are shown in Table 2. To date, there are no reported plans to initiate indigenous programmes for major platforms. This can be attributed to both the absence of economies of scale and less-than-guaranteed export prospects, with SAF the only secure client for such complex systems and platforms.

Table 2: Singapore Major Arms Procurement, 1980-2017

Year Purchased	Supplier Country	Item	Quantity	Remarks
1980	USA	A-4S Super Skyhawk ground attack fighters	16	
1980	USA	F-5E Tiger II fighter-bombers	6	US$34 million deal
1981	USA	F-5F Tiger II fighter-bombers/trainers	3	US$16 million deal
1983	USA	A-4S Super Skyhawk ground attack fighters	8	
1983	USA	E-2C Hawkeye airborne early warning and control aircraft	4	US$437 million deal
1984	USA	F-5E Tiger II fighter-bombers	6	
1985	USA	F-16A/B Fighting Falcon multi-role fighters	8	US$280 million 'Project Peace Carvin I' deal
1986	Germany (West)	MGB-62 corvettes	6	

1986	USA	F-5E Tiger II fighter-bombers	5	
1986	USA	KC-130H Hercules refuelling aircraft/tactical transport	1	
1987	USA	C-130H Hercules tactical transport aircraft	1	
1987	USA	F-5F Tiger II fighter-bombers/trainers	3	
1989	USA	A-4B Skyhawk ground attack fighters	24	
1991	Sweden	Landsort-class mine countermeasures vessels	4	
1992	USA	F-16C/D Fighting Falcon multi-role fighters	18	US$890 million ‘Project Peace Carvin II’ deal
1994	USA	CH-47D Chinook heavy-lift helicopters	6	
1994	USA	F-16A/B Fighting Falcon multi-role fighters	8	US$280 million ‘Project Peace Carvin I’ deal
1995	Sweden	Sjöormen-class submarines	1	
1996	USA	F-16CJ Fighting Falcon multi-role fighters	12	First leased and then purchased
1997	Sweden	Sjöormen-class submarines	3	
1997	USA	F-16CJ/DJ Fighting Falcon multi-role fighters	12	US$350 million ‘Project Peace Carvin III’ deal
1997	USA	KC-135 Stratotanker refuelling aircraft	4	US$280-500 million ‘Project Peace Guardian’ deal
1998	USA	CH-47SD Chinook heavy-lift helicopters	6	

1999	USA	AH-64D Apache Longbow attack helicopters	8	Part of US$629 million 'Project Peace Vanguard' deal
1999	USA	CH-47SD Chinook heavy-lift helicopters	4	
2000	France	La Fayette frigates	6	US$750 million deal (part of US$1.6 billion 'Project Delta')
2000	USA	F-16D Fighting Falcon multi-role fighters	20	'Project Peace Carvin IV' deal
2001	USA	AH-64D Apache Longbow attack helicopters	12	US$617 million 'Project Peace Vanguard' deal
2005	Sweden	Västergotland-class submarines	2	US$128 million 'Project Northern Light' deal
2005	USA	F-15SG Strike Eagle multi-role fighters	12	US$1 billion 'Project Peace Carvin V' deal
2005	USA	S-70B Seahawk shipborne helicopters	6	
2007	Germany	Leopard-2A4 main battle tanks	182	
2007	USA	F-15SG Strike Eagle multi-role fighters	12	US$1 billion deal
2007	USA	G-550 airborne early warning and control aircraft	4	Ordered and delivered via Israel; mission systems fitted in Israel
2008	USA	M-142 HiMARS multiple rocket launcher	18	
2010	USA	F-15SG Strike Eagle multi-role fighters	8	
2012	Germany	Leopard-2A7 main battle tanks	12	
2013	Germany	Type-218SG submarines	2	

2013	USA	S-70B Seahawk shipborne helicopters	2	
2014	Spain	A330 MRTT refuelling aircraft	6	
2014	USA	F-15SG Strike Eagle multi-role fighters	8	
2016	USA	CH-47F Chinook heavy-lift helicopters	10	
2017	Germany	Type-218SG submarines	2	

Source: SIPRI Arms Transfers Database, at: https://www.sipri.org/databases/armstransfers (accessed on 22 October 2018).
Note that the Carvin I-V programmes constitute the republic of Singapore Air Force procurement of US F-16 fighter aircraft, including the provision of training at the Luke Air Force base in Arizona.

3. Unique defence-industrial 'ecosystem'

Singapore's defence-industrial ecosystem is framed by reference to an expanded definition of national security. The model was likely influenced by Japan's 'comprehensive' security approach that has been in place since the beginning of the 19th century Meiji era (1868-1912).[11] The Japanese interpreted security as a composite of economic, technological, military, diplomatic, political and related fields of competence. Comprehensive security embraces defence, including defence industrial capability, but this represents just one of multiple security competences, rather than equating to national security itself. Singapore has a similar Total Defence concept that has been forged on the same national security anvil, covering the conventional elements of economic, civil and military defence, but additionally there are elements of social and psychological defence, reflecting the country's diverse ethnic minority groupings From the perspective of this chapter, Total Defence reflects the Singapore government's desire to interlace the defence (security) and economic (prosperity) objectives, to ensure that defence investment is not quarantined from the wider economic community. It is, therefore, instructive that across ST Engg's four subsidiary companies, only kinetics is dedicated to military outputs. The other three, aerospace, maritime and electronics, are civil-military, and functionally organised so that skills and learning acquired on military programmes are transfused into ST's wider commercial and more profitable activities.[12]

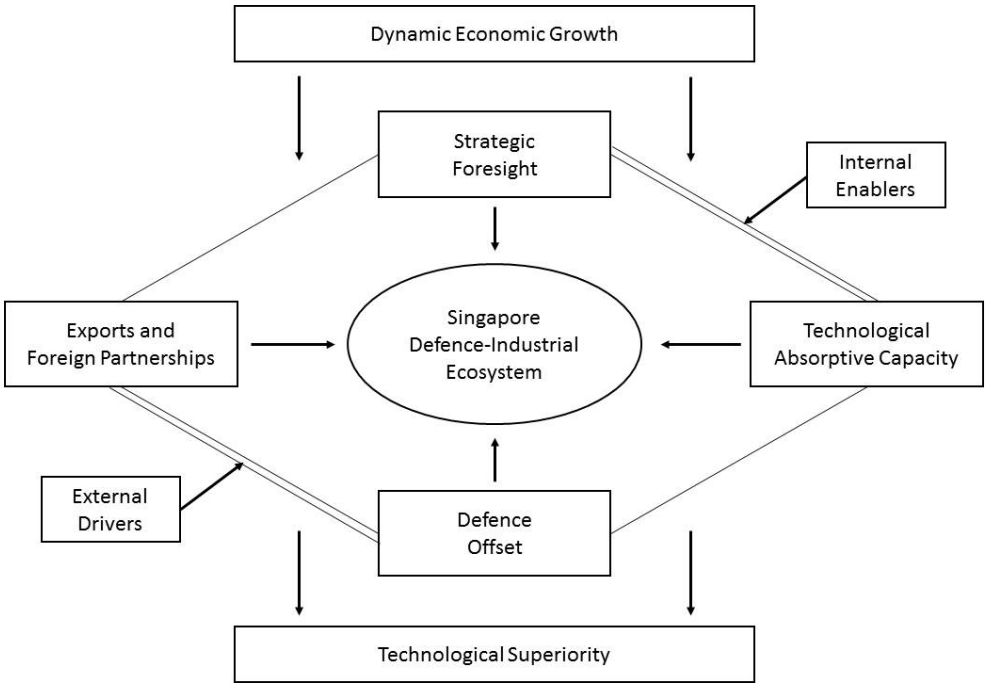
Located within the Total Defence space is Singapore's 'defence ecosystem'. The concept was first coined by Quek Tong Boon (Deputy Defence Secretary for Technology and Transformation) in 2006. He defined it in terms of the

interdependency and co-evolution between the country's users, developers and producers of defence equipment.[13] Although the 'users' (i.e. the SAF) do participate in the choice of system design, logistical requirements and other related issues, its absence of operational combat experience limits the extent of its contribution, and likely negatively impacts on defence export prospects, also. In the context of this chapter, therefore, perhaps a more relevant concept is a Singaporean 'defence-industrial ecosystem', reflecting the quadrilateral stakeholder relations between: firstly, policymakers and funders (government); secondly, developers, comprising the labyrinth of defence-related R&D organisations; thirdly, producers (defence industry); and, fourthly, the network of trading partners and collaborators, operating within a globalised environment. Whilst there also exists a high level of interdependence between each of these constituent parts, importantly, the defence industry assumes the role of pivotal player in transforming ideas and designs into 'teeth end' technological capability; indeed, it endorses the notion posited by Bilveer Singh that the defence industry is the fifth (military-related) arm of Total Defence.[14] At the core of Singapore's defence industry is ST Engg, sponsoring the cumulative and evolutionary incubation and then maturity of indigenous defence technologies into a 'secret technological edge' for use against potential aggressors.[15] This approach eschews the comprehensive development and production of platforms, but rather aims to develop high technology defence systems that can be integrated into platforms procured from overseas. However, to ensure this technological edge acts as a deterrent, its possession and deployment must be secret. This strategic posture was aptly described by Singapore's former President, S.R. Nathan, when he stated: "we must develop indigenously…a technological edge…and this must be developed secretly - in strict secrecy - so that nobody knows the kind of defence-related technology and capability that we have developed".[16] Yet, logically, the possession of a technological edge must be an 'open secret', as to deter potential aggressors they must be aware of the profound defence capability that faces them, albeit that the precise configuration and impact remains unspecified

Figure 2, below, illustrates that the promulgation of an indigenous defence technological edge that emerges through internal interactions of the ecosystem's quadrilateral relations, particularly government-inspired strategic foresight and R&D investment. The defence-industrial ecosystem also comprises external drivers, such as overseas trading partners and collaborators (exposure to competitive pressures) and defence offset (technology infusion), which additionally contribute to the technological 'superiority' goal. A further influence comes from the aforementioned defence policy imperative that places a premium on technology multipliers through organic and overseas procurement of advanced weapons systems as a means of compensating for the restricted supply of military personnel. This search for technological superiority is a characteristic of Singaporean developmental strategy, implemented through the government's

interventionist role. It is a process of proactive central planning in which the economy has been nurtured to progress rapidly through successive development stages from agriculture, manufacturing, services and finally knowledge-intensive transformation. The strategy encourages cultivation of incipient high technology industries, such as information, computer, telecommunications, defence and aerospace. The development of these 'strategic' industries has been catalysed through foreign direct investment and technological partnerships. Government policy emphasis has been on access to overseas technology to sustain and generate local skills and innovation. The result of this development strategy has been to secure a civil-military status best described by the metaphor, 'rich nation, strong army'.[17]

Figure 2: Constituent components of Singapore's defence-industrial ecosystem



Source: authors

Strategic foresight

The Singapore government has always played a proactive role in identifying and sponsoring the growth and development of 'leading' sectors within the local economy. These may be described as growth poles, industrial pillars, champion industries, or most often 'strategic' industries. Such industries are viewed as powerful development catalysts, because of their important contributions to skilled employment, high sales, enhanced value added, knowledge-intensive output and strong backward industrial linkages. This interventionist development

process goes back to the early post-independence era, but accelerated in 1991 by the launch of a Strategic Economic Plan.[18] The Plan highlighted eight strategic thrusts, including human resource development, international partnerships and investment, R&D and the promotion of industrial and technological clusters. Complementing the Strategic Plan was a Science and Technology Plan that invested billions of Singapore dollars into increasing the numbers of researchers and R&D capacity in both the civil and defence sectors. Defence and aerospace were viewed as integrative strategic industries, enjoying technological synergies that straddle the civil-military divide. The Economic Development Board (EDB) acted as the Singaporean equivalent of Japan's post-WWII MITI (Ministry of Trade and Industry) that sought to identify and orchestrate the development of strategic industrial sectors. For example, the EDB developmental model facilitated the creation of an advanced industrial aerospace cluster at the site of an old WWII Seletar airfield. This has attracted huge numbers of local and foreign high technology players, including global companies like General Electric (US), Lockheed Martin (US), Boeing (US), Thales (France), and Rolls-Royce (UK); the latter establishing assembly and testing facilities for its Trent family of aero-engines, creating over 2,000 skilled jobs.[19] EDB's 'visible hand' intervention in fostering the Seletar cluster proved a major instrumental factor in the project's success. Horizon scanning is a further crucial task of the EDB in its role of identifying the future emergence of new and dynamic military and/or civil strategic sectors.

A case in point is the space industry. Singapore was a late entrant into this high technology industry, but was attracted by the obvious high skill and capability spin-offs. Its entry started modestly with a 2003 locally built satellite X-SAT. Since then, Singapore has launched a series of different small satellites ranging from 1kg to 400kg in weight, and notably involving local university students in the R&D process.[20] Presently, the local space industry employs 1,000 people across 30 companies. Its principal sponsor is the EDB, which established an Office for Space Technology and Industry (OSTIn) in 2013. Following the tried and tested approach of harnessing local and foreign expertise, Singapore's space quest has enjoyed some early successes. For example, NTU scientists have developed a new tiny radar camera chip that is 100 times smaller than the current 200kg radar cameras, yet capable of capturing radar images regardless of light or weather conditions; it is touted to be about 20 times cheaper to produce and consumes 75 per cent less power.[21] In January 2018, DSO National Laboratories and NUS jointly launched the Satellite Technology and Research Centre (STAR) to develop distributed satellite systems capabilities, focused on multiple small satellites, each weighing a tenth of conventional satellites, either in formation or constellation. The new centre will also train undergraduates and graduate students to meet the manpower needs of the country's space industry.[22] DSTA and ST Egg

have also partnered in early 2018 to acquire a new earth observation satellite, DS-SAR, with a synthetic aperture radar-imaging payload.

Technology Absorptive Capacity

The concept of technological absorptive capacity has regard to the spectrum of capabilities in an economy that facilitate local innovation. In the main, this includes possession of highly skilled scientists, engineers and design staffs, knowledge institutions, technology-based universities and specialised institutes, supply chains and R&D capacity. Since independence, Singapore has prioritised investment into human capital, created the development of world class universities, promoted overseas education of its best scholars and sought to nurture the rapid evolution of small medium size enterprises that act to deepen development of innovative supply chains and R&D. Due to its small size, and hence lack of scale opportunities, Singapore has pursued ambitious plans to elevate the role of technology progress, especially on the defence science and technology front. "Singapore can lead in defence technology, even though we are small," said Defence Minister Ng in 2017, revealing that the country has a 5,000-strong community of defence engineers and scientists, and has plans to fund a 40 per cent increase in scholarships and awards by 2025.[23] A critical push factor in positioning Singapore as a global player in defence technologies is the Defence Science and Technology Agency (DSTA). The Agency is a statutory board under MINDEF, whose aim is to harness and exploit science and technology to provide technological and engineering support for the defence and national security needs of Singapore. It implements defence technology plans, acquires defence equipment and supplies and develops defence infrastructure for the Ministry. DSTA works closely with DSO National Laboratories. This is Singapore's largest defence R&D organisation, aimed at developing technological solutions to sharpen the cutting edge of Singapore's national security. These R&D establishments operate as part of a technological web of local universities, the Agency for Science, Technology and Research (A*STAR), and other related government agencies, such as the Government Technology Agency of Singapore (GovTech), the Cyber Security Agency of Singapore, the National Research Foundation, and also the EDB.

The Singaporean Government does not disclose annual expenditure on defence R&D. However, in November 2001, the then Deputy Prime Minister and Defence Minister, Dr Tony Tan, revealed that Singapore spends about 4 per cent of its defence budget on long-term R&D endeavours.[24] This relatively high proportion seems about right, given Singapore's priority on the development of frontier defence technologies. The 4 per cent proportion applies to direct defence R&D through MINDEF's leading institutions, and in particular the DSTA and DSO National Laboratories. Additionally, ST Engg invests in R&D, though it is

difficult to determine how this is split between the military and civilian sectors, especially given the advanced state of dual-use technologies developed and produced by the company. The ST Electronics CEO and President, Seah Moon Ming, stated in late 2007 that 7 per cent of the company's annual revenue was spent on customer-funded research; for instance, when SAF pays ST Engg to source and develop specific solutions and allows it to use the technology for purposes beyond the original project. Internally, ST Engg allocates about 3 per cent of its annual revenue for R&D, though certain divisions such as electronics spend more. Seah argues that R&D investment is a critical corporate dynamic, and if it falls below 5 per cent, then there is an inability to renew products, systems and capabilities.[25]

A third stream of defence-related R&D funding derives from the Singapore Government R&D allocations to university and polytechnic institutions. Since 2002, the budget supporting collaboration between premier local R&D institutions, such as A*STAR and ST Engg, was S$80mn. Additionally, DSTA established a S$20mn Technology Innovation Fund, extending defence-related R&D funding to small and medium enterprises.[26] More recently, in early 2014, MINDEF collaborated with Nanyang Technological University to establish an Office of Research and Technology in Defence and Security to coordinate the over 120 defence and security projects worth about S$130 million across five university research institutions.[27] ST Engg also collaborates with local universities in fostering R&D that has civilian and military applications. For example, in May 2012, ST Kinetics invested S$3 million in Singapore's Republic Polytechnic to establish the Advanced Composite Engineering Lab (ACEL). This laboratory specialises in composite material science research and production, and is possibly the first in Southeast Asia to specialise in natural fibre studies. The defence-industrial ecosystem also actively promotes overseas collaboration to obtain expertise from foreign research institutions. For example, the Campus for Research Excellence and Technological Enterprise (CREATE) was established at the National University of Singapore (NUS) in 2007 by the National Research Foundation to forge security-related R&D collaboration between local and premier foreign research institutions.[28] In February 2017, the National Cybersecurity R&D Laboratory (NCL) was launched at NUS with the support of the NRF's National Cybersecurity R&D Programme, serving as a test-bed for creative cybersecurity solutions and a one-stop platform providing ready-to-use tools and environments for cybersecurity research and training.

Contemporary R&D programmes reflect pragmatism regarding Singapore's long-term national security perceptions, foreseeable market opportunities and in no small part are driven by Singapore's long-term concern about its military manpower woes. Accordingly, policy emphasis on promoting capability in key niche R&D areas, covers, for instance: 1) emerging technologies including

artificial intelligence (AI), robotics, cyber and additive manufacturing (or more commonly known as 3D printing); 2) unmanned systems; and 3) commercial space technologies. Towards the ultimate objective of indigenising R&D programmes, MINDEF initiated a seed grant of S$45 million per annum for DSTA and DSO National Laboratories to undertake AI and robotics R&D.[29] R&D programmes in these niche areas seek to exploit the latent expertise at the six local universities, especially in unmanned systems and related technological innovations, and there have been early successes. For example, NUS researchers have developed an Aerial Unmanned Vehicle – MantaDroid – that looks and swims like a manta ray, using only single motors and flexible fins to propel it through water.[30] NTU has been studying how to develop drones that act as air traffic management systems.[31] Separately, DSTA and ST Engg are collaborating to develop technologies to minimise manning requirements on board the navy's *Independence*-class Littoral Mission Vessels (LMVs). Additionally, DSTA and ST Kinetics unveiled in late 2016 a 10-variant Belrex family of Protected Combat Support Vehicles (PCSVs), tentatively targeted at the export market.[32] Finally, to publicise Singapore's niched capability in the development and production of unmanned aerial, ground and maritime systems, DSO National Laboratories is known to have developed the Meredith 400 autonomous underwater vehicle (AUV) for mine countermeasures operations.

Exports and foreign partnerships

Singapore is not one of the world's major defence exporters, not least because overseas arms sales have proved something of a balancing act, with the economic benefits derived from such exports often subordinated to the government's diplomatic imperative of maintaining a neutral stance in international affairs, generally, and conflict, specifically. As a result, export performance has been mixed. In the MRO field, Singapore is one of the world's leading providers, especially in aerospace, but across the broader military sectors performance has been less spectacular. Table 3 shows some notable patterns. During the Cold War, nearly all exports comprised ST Marine built naval vessels, such as simple coastal patrol and landing craft, along with other miscellaneous fleet auxiliaries; yet, the numbers built were modest. It was only after the Cold War ended that arms exports diversified beyond the naval sphere to include some land systems. This appeared to be at the cost of naval export volumes, even if some limited export successes were achieved in sales of more advanced vessels. For instance, one *Endurance*-class LPD (HTMS *Ang Thong*) was built for Thailand, but the option for a second unit was never exercised due to Bangkok's funding constraints. This was the largest warship ever exported by Singapore. A far smaller export programme was the four-ship *Al-Ofouq* class offshore patrol vessel sale to the Royal Navy of Oman, which was completed in 2016.

Table 3: Singapore's Major Arms Exports

Year	Recipient	Weapon	Quantity	Remarks
1969	Malaysia	*Duyong*-class diving support tender	1	
1973	The Philippines	*Bataan*-class patrol craft	2	
1976	Brunei Darussalam	*Waspada*-class missile fast attack craft	3	
1978	Kuwait	LC-32m landing craft	3	
1979	Thailand	*Chula*-class fleet tanker	1	
1980	Oman	*Saba Al Bahr*-class landing craft	1	
1982	Oman	*Saba Al Bahr*-class landing craft	2	
	UAE	*Baracuda*-class support ship	1	
1983	Bangladesh	PB-46 patrol craft	2	
1984	Sri Lanka	*Abheetha*-class cargo ship	3	Second-hand
		Mahawele-class support ship	3	Second-hand
1985	Sri Lanka	LC-33m landing craft	2	
1986	India	*Tara Bai*-class patrol craft	6	Including 4 units built in India
	Sri Lanka	*Hansaya*-class transport craft	2	
	UAE	*Al Feyi*-class landing craft	1	
		Baracuda-class support ship	2	
1987	Brazil	*Grajau*-class patrol craft	4	
1988	Sweden	*Smit Manila* cargo ship	1	*Uto*
1990	Sri Lanka	LC-33m landing craft	2	
1993	Kuwait	*Al Tahaddy*-class landing craft	2	
1995	Papua New Guinea	Standard 120mm mortar	3	
1996	Indonesia	FH-88 155mm towed field howitzer	5	Possibly second-hand
	Papua New Guinea	Vosper Type-A/B	3	Second-hand
2000	Sri Lanka	Standard 120mm mortar	9	Second-hand

2002	Indonesia	*Jupiter*-class diving support tender	1	Second-hand
2007	Nigeria	FPB-38 patrol craft	2	From Malaysian production line
	UAE	SRAMS 120mm self-propelled mortar	48	
2008	Thailand	Bronco all-terrain tracked vehicle	10	
	Thailand	*Endurance*-class landing platform, dock	1	
	United Kingdom	Bronco all-terrain tracked vehicle	115	Designated Warthog
2011	UAE	SRAMS 120mm self-propelled mortar	72	
2012	Oman	*Fearless 75*-class offshore patrol vessel	4	Project Al-Ofouq
	Unknown	SRAMS 120mm self-propelled mortar	25	
2015	UAE	SRAMS 120mm self-propelled mortar	24	

Source: Stockholm International Peace Research Institute (SIPRI), *Arms Transfers Database*, at: https://www.sipri.org/databases/armstransfers (accessed on 16 September 2018)

Other recent export successes include a major contract to supply a modified variant of the ST Kinetics' Bronco all-terrain tracked carrier (ATTC), designated Warthog, for the British Army's deployment in Afghanistan. Singapore's 120mm Super Rapid Advanced Mortar System (SRAMS) also found success with the United Arab Emirates, a return customer, ordering 96 units in total. There have also reportedly been unspecified sales, especially of small arms and light weapons (SALWs), to foreign clients. Singapore-made SALWs have seen some modest export successes, mainly to the developing world. But not all such sales have been properly documented, meaning that Singapore's SALW exports could be more than what has been reported thus far. For example, unknown quantities of Singapore-made SALWs, such as the Armbrust infantry light anti-tank and personnel weapons, found their way into the conflict-ridden Balkans in the 1990s.[33] In 1998, Chartered Industries of Singapore reportedly shipped a whole prefabricated arms factory to Myanmar and established, with Israeli consultancy assistance, the military junta-ruled country's SALW development and production capacity.[34] In 2005, Papua New Guinea authorities launched a probe into an

illegal consignment of Singapore-built SAR-21 assault rifles along with six 30-round magazines and 500 rounds of 5.56mm SS109 ammunition, which were seized by Air Nuigini security personnel at Jacksons International Airport.[35]

In the late 1990s and early 2000s, Singapore embarked on a quest to carve out new overseas markets through a series of mergers and acquisitions. However, these efforts were characterised by a number of high profile failures to clinch major deals, such as the Bionix IFV bid for the US$7bn Army Interim Armored Vehicle programme. ST Engg also sought to acquire American firms, including ST Marine's 2002 acquisition of VT Halter Marine and the ST Engg 2009 acquisition of US subsidiary, VT Miltope. Such mergers and acquisitions reflect ownership of foreign entities that allow a direct 'in' to the US market. Another form of tie-up with foreign industrial capability is via technology partnerships. Singapore has performed exceedingly well, here, collaborating with other 'small' states, such as Israel, in niched business areas that include military aircraft retrofitting, upgrading and civilian conversion. ST Engg has been awarded open competition contracts to upgrade C-130J heavy lift aircraft belonging to the Turkish and New Zealand air forces. This is a capability that ST Aerospace has developed, even though it does not produce aircraft (with the notable exception of the EC-120 Colibri light helicopter through a joint venture with China and France, enjoying some export success). ST Aerospace has also achieved major successes in the upgrade of legacy fighter jets serving some foreign air forces. For example, it tied up with other foreign firms in 1999 to upgrade Brazilian and Turkish F-5 air force jets. Additionally, ST Aerospace worked with Thai Aviation Industries on the Falcon One cockpit and avionics upgrade programme to modernise part of the Royal Thai Air Force's fleet of F-16A/B Fighting Falcon multi-role fighter jets in 2006.

Defence Offset

Beginning in the 1970s, Singapore embarked on the task of constructing a strong and diversified domestic defence-industrial base, and the authorities quickly recognised the contribution that defence offset could make,[36] especially with respect to fostering creation of capacity and enhancing worker skill sets. MINDEF followed a non-typical offset approach, and instead of designing and publishing a prescriptive policy, allowing overseas defence contractors sight of the regulations, the policy document was only available for internal consumption. This means that the offset authority and the offshore vendor commenced negotiations with a clean sheet of paper on each and every procurement programme. Predictably, the Singaporean bargaining position was always rigorous and demanding, but there would likely be greater opportunities for compromise, dependent upon the scale of procurement. From modest beginnings, Singapore's defence offset investments have grown considerably, and most offset

observers would argue that the country now hosts one of the world's most successful offset regimes.

The earliest offset programme occurred in 1970, when Chartered Industries agreed a nine-year deal to license produce 80,000 American M16 assault rifles for the SAF.[37] In the decades since then, Singapore has engaged in far more ambitious offset agreements. For example, the naval programme to build six *Formidable* class stealthy frigates based on the French *La Fayette* design was linked to an offset arrangement that not only allowed Singapore to build five of these warships locally, under licence, but the country's primary defence technology institutions, the Defence Science and Technology Agency (DSTA) and Defence Science Organisation (DSO) National Laboratories, collaborated with their French partners on frontier stealth technology R&D. As would be expected, these 'silver bullet' defence R&D programmes are undertaken in complete secrecy. A further interesting maritime case study on the strategic approach MINDEF planners adopt when acquiring and then absorbing the overseas technologies in the local development of defence capability relates to submarine procurements. Singapore's initial acquisition of submarines were the A12 *Sjöormen* class, all acquired second-hand from the Royal Swedish Navy, mainly to serve as training platforms to support RSN attempts to build an undersea warfare capacity. The boats were refurbished and tropicalised for the local operating environment, and then recommissioned into RSN service as the *Challenger* class. The second batch of submarines acquired from Sweden was the pair of A18 Västergotland class boats, which were larger than the A12s, and built in the 1980s, hence newer. They were refurbished and modernised to the same standards as the Swedish Navy's *Södermanland* class, with an AIP section inserted midships, before being recommissioned as the *Archer* class. ST Engg Marine gained considerable expertise from interactions with Swedish submarine engineers, especially partnering on the integration of modern electronic systems. This progression of learning has enabled Singapore to scale the specialised submarine technology ladder in preparation for the next higher learning stage associated with the more recent acquisition of the navy's customised Type-218SG submarines built by the German shipbuilder TKMS.[38]

4. Future prospects

This chapter has explored and evaluated the principal attributes of Singapore's unique defence-industrial ecosystem. The successful push for defence industrialisation was spurred by strategic vulnerability. The interpretation of national security that highlights the contribution of economic, technological and military components ensured that the high cost of defence and aerospace development was funded by robust economic growth. Moreover, the search for technological security was facilitated by a parallel policy emphasis on promoting

synergistic civil-military industrial and technological integration. The government's proactive support of strategic industries sponsored via intensive investment into the creation of deep technological absorptive capacity, especially high level R&D capability, has powered the defence and aerospace sectors into scaling higher technology stages. At the core of this defence-industrial ecosystem is ST Egg, which, through elevated levels of competitiveness and innovation, has catalysed rapid market expansion, and positioned the company at 40th in the world's top 100 defence companies. The development of Singapore's defence-industrial base has also been assisted by infusion of advanced technologies and learning through the process of defence offset. The diffusion and absorption of these offset-related technology transfers has proved effective principally because of the spectrum of diverse technology capabilities permeating Singapore's technology absorptive capacity. The one disappointing component within the quadrilateral defence-industrial ecosystem as conceptualised in this chapter is defence export performance. This will likely see dramatic improvement in future years, as ST Engg belatedly forges an international 'brand'. The company can be expected to pursue a nuanced and niched civil-military focus to capture not only the export of specialised high value upgrades, MRO and conversion programmes but also broader security-related sales of space, aerospace and artificial intelligence systems. There is no logic in tampering with the policy mechanics behind Singapore's defence industrial success, and through continued local and overseas strategic partnerships there is the expectation that the success story will endure. The chapter ends by asking the obvious question as to whether the model is transportable. It is possible, but would require emulation of not just the policy frameworks and institutional structures but also the cultural dynamics.

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[13] Sourced from personal correspondence with Robert Karniol (1 November 2018), who supplied his seminal article, 'Industry Briefing: Singapore Defence Ecosystem', *Jane's Defence Weekly*, February 2006. It is also instructive that Quek Tong Boon interpreted the notion of a defence ecosystem as malleable. Citing from Karniol's 2006 article, Quek Tong Boon explained that…"At the core [of this defence ecosystem] are MINDEF, the SAF, DSTA and DSO, then the two Temasek laboratories, our defence industry and dual-use R&D expertise that we can tap from our tertiary institutions and research institutes. We also consider our international partners and relevant parts of the private sector as integral to our defence *technology* ecosystem.[author emphasis added]"
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Chapter 25: Singapore’s defence-industrial ecosystem

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