POINTER MONOGRAPH NO. 5

Integrated Knowledge-based Command and Control *for the ONE SAF*

Building the 3rd Spiral, 3rd Generation SAF

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LTC TAY CHEE BIN is currently the Head of SAF Centre for Military Experimentation. He believes that as lethality, area of influence and specialisation of combat forces increase, coupled with blurring of boundaries between conventional warfare and OOTW, a shift in paradigm for command and control of military operations is required. He believes that network sciences and complexity theory offer new perspectives and C2 model necessary to deal with the increasing complexity of military operations. LTC Tay holds Master of Science in Defence Technology and Systems from the National University of Singapore and a Master of Science in Computer Science from the US Naval Postgraduate School. His previous appointments include Commanding Officer of a Signal Battalion and Branch Head in JCISD.

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FOREWORD

The transformation to the 3rd Generation Singapore Armed Forces (SAF) is well underway. We began by creating capacity to change and allowing space for new developmental ideas and operational concepts to be developed. These were captured in two monographs published in 2003. Four years on, these ideas and concepts continue to underpin our capability development. Precision weapons, unmanned systems and Integrated Knowledge-based Command and Control (IKC2) technologies were identified as three key areas of growth and we have made significant progress in all of these areas. IKC2, in particular, has enabled the move towards a more integrated and networked SAF.

The vision is to build *ONE* SAF. Having steadily built up the foundational pillars in the Army, Navy and Air Force through the early years, we can now focus our efforts beyond modernising platforms and capabilities along Service lines towards stronger cooperation and interdependence across the Services. The 3rd Generation SAF would be more integrated, networked, cohesive and singular in its mission focus – which remains to deter threats to our security and sovereignty; and to be ready and capable across a spectrum of operations to protect our national interests.

We have the *Technologies* and *People* that allow us to move firmly and boldly towards this. Ideas have been translated into capabilities, and plans into action. In the area of technology, leading edge capabilities are being assimilated into platforms and systems in a spiral development approach, as innovative future concepts are being evolved. For our people, new competencies, organisational structures and work processes are being put in place. The emphasis is to nurture and engage our people, so that they can continue to be competent and committed in their responsibilities towards mission and organisational excellence in the new security environment.

This monograph describes our force transformation journey thus far in the area of IKC2. It accentuates the important work that is being done to build stronger networks and greater integration across the SAF. More than this, it opens new opportunities and attitudes towards more open and matrixed systems, building new linkages and interoperabilities at the system level between organisations and systems, and across domains. These are the emerging trends, concepts and ideas that will shape the 3rd Generation SAF.

I hope you will enjoy this monograph.

LG DESMOND KUEK
Chief of Defence Force

DISCLAIMER

The opinions and views expressed in this work are the authors' own and do not necessarily reflect the official views of the Ministry of Defence.

1 INTRODUCTION

CAPACITY TO CHANGE – OUR IMPERATIVE

At the peak of its business sagacity, Silicon Graphics Incorporation (SGI) was touted as the emerging star of the IT industry with an impressive revenue of US$2.2 billion dollars recorded in Jun 1995. The then-IT giant achieved astounding success with its advanced three-dimensional (3-D) graphics computers that played a starring role animating the fearsome dinosaurs in Jurassic Park. Nintendo was also using the same technology to design a new generation of arcade-like game machines. SGI rocketed to fame and fast fortune on the flashy technology of powerful computer workstations and servers with 3-D graphics so realistic that they became the computer of choice for Hollywood filmmakers, engineers, and scientists. However, its impressive escalade to success was short-lived. SGI's plight became evident in a spate of downward spirals that started shortly after 1997. SGI's market capitalisation dwindled from a peak of over US$7 billion dollars in 1995 to just US$120 million at the time of its de-listing from the New York Stock Exchange. They filed for bankruptcy in 2005.

Business analysts attributed various factors to the fall of SGI, but the most compelling was the failure to anticipate the challenge posed by a seemingly insignificant competitor: ***the omnipresent PC.*** The emergence of desktops with off-the-shelf Intel chips and Microsoft's Windows NT were starting to do more of the complex graphics jobs that workstations using UNIX software, such as SGI's, routinely tackled. Overtime, this inability to respond led to its decline.

Business history is replete with cautionary tales of how the failure to anticipate market changes can spell disaster for the corporate giants, and how success is merely a transient state of affairs. The dynamism of market forces dictates that one must constantly evolve or reinvent oneself to remain relevant and competitive.

This truism is equally pertinent in the military domain, with one crucial difference. After a business fails, its employees, customers and investors can always move on to a different firm. It is much harder for citizens to move on to another country after their homeland fails to keep up in the struggle for security. The stakes are much higher. The rapid pace of change and the growth of knowledge, coupled with the interconnectedness of the 3rd Generation SAF will introduce heightened levels of complexity, creating new tensions that will constantly challenge current processes and mindsets. To succeed, we need more effective models to implement better organisational principles and practices.

TOWARDS AN AGILE ORGANISATION – KNOWING WHAT IT TAKES

One such model was articulated in the first *POINTER* monograph (2003) – "Creating the Capacity to Change (C2C): Defence Entrepreneurship for the 21st Century". In it, we discussed the need for a major cultural change alongside existing organisational structures to thrive in an increasingly complex and dynamic world. Such organisational adaptivity is needed to allow SAF the capacity to evolve in an ecological manner through mutual interaction, internal adaptability, and rapid response – all of which are vital to creating and nurturing a sustainable competitive advantage and high performance over the long term.

Creating C2C Space

The key organisational lesson from complex adaptive systems is that leaders and managers should find ways to allow creativity to emerge naturally within their organisations rather than impose pre-conceived solutions on their subordinates. Hence, to bring out the best in our people, organisations need to give them space – physical space, time resources or intellectual bandwidth – to be creative. The task of leaders and managers is no longer that of coming up with all the answers, but of creating space and creating the right conditions for the interactions and relationships within that space.

Source: Excerpts from C2C Monograph, p16

The core idea is about empowering our people by encouraging a spirit of "defence entrepreneurship" to facilitate constant change and innovation in ***strategy, capability and warfighting.*** This is achieved by equipping our people with the right cognitive skills and attitudes, providing a knowledge network and community for idea development, and building a competitive internal marketplace so that the most promising ideas will thrive and be implemented.

IKC2 – SAF'S ENGINE OF TRANSFORMATION

On the operational front, the IKC2 warfighting concept epitomises the need for such adaptivity and innovation. IKC2 is not about technological breakthroughs alone. In fact, the potential of IKC2 is predicated on how the innovativeness of our people can be harnessed to make the right decisions and enable the right actions in a network-centric, knowledge-based environment.

To achieve this, we believe that a defence entrepreneur spirit must continue to be nurtured as advocated in the C2C monograph to bring about changes in thinking and innovative application of technologies that are integral to realising new IKC2 warfighting concepts. While the spirit behind C2C must remain, IKC2 as a warfighting concept must evolve and be sharpened to adapt to change and uncertainty. This will be a perennial endeavour to ensure a sustainable and competitive edge for the SAF.

Hence, this monograph is an attempt to elicit thoughts and challenge prevailing mindsets, by elucidating new possibilities that have emerged over time. The intent however, is not about defining an envisioned end-state for implementation. Rather, the approach is to articulate ***transformational thinking and highlight key implications*** that may potentially drive the design and development of 3rd spiral capabilities.

Organised into ***two sections***, the monograph provides perspectives of how IKC2 will progressively be realised. It looks into the future to shape present waypoints.

In the first section "***IKC2 – Through a Different Lens***", we begin by identifying some of the emerging trends that offer new opportunities and paradigms of thinking about operations in the 3rd spiral. Building upon these new paradigms, we will discuss the long-term implications and strategies to accommodate such emerging demands. Three key implications that are pivotal to 3rd spiral development will be expounded.

In the second section "***Building upon a Strong Foundation***", we provide a perspective of the 1st spiral foundational work put in place to realise future possibilities. This encompasses initiatives not only in technical capability development, but also training and equipping people with the requisite skill sets, and sharpening existing processes to build up capabilities more efficiently and effectively. It provides an account of practical progress made thus far, beyond mere theoretical concepts.

Section One

IKC2 – Through a Different Lens

2 POSSIBILITIES, POTENTIAL & IMPLICATIONS

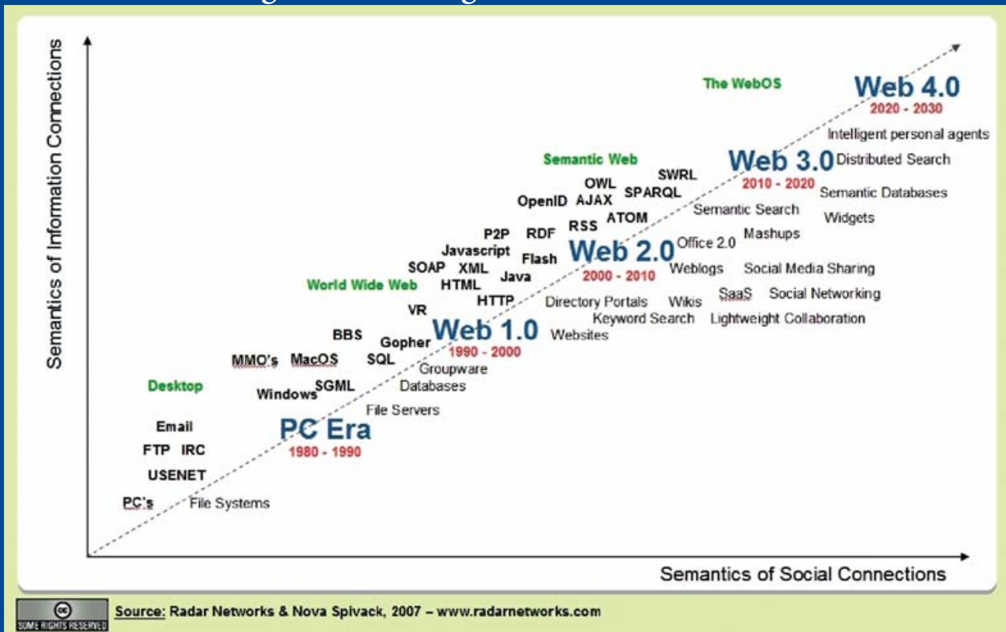
THE COG IN THE WHEEL

The Internet is arguably the most salient technological marvel in the last millennium that has captured the public eye and changed our lives. Its deep impact stems largely from its disruptive influence on how we think about distance and time, by creating the environment where users can develop their own digital media for global sharing. Since the inception of the web (Web 1.0), it has spurred the development of innovative applications and spun emergent behaviours through platforms, such as the Google search engine, eBay virtual auction house and Expedia's web-based travel service. It has given new meaning to social networking in the likes of MySpace, Bebo, Xanga, Friendster, and orkut. More recently, the Internet has become the *sine qua non* of the video viewing website YouTube for user-submitted content in major events, including the CNN YouTube Presidential Debates.

The ***Power of Knowledge*** is the core driving force that is propelling this rapid transformation of Web 1.0 (providing web connectivity), to the current Web 2.0 (advent of social networking). Beyond this, it will continue to empower even greater levels of information and social connectivity in an emerging web called Web 3.0 (intelligent Web), which some scientists[1] are suggesting is the dawn of the Semantic Web.

This typifies the interconnectedness of the knowledge economy and the interdependencies of an increasingly complex environment. This in turn has changed all aspects of modern life – how we live, how we work and how we fight. Improvements in technology have always had an immediate impact on warfare. The art of war rarely remains static. Even in the realm of irregular warfare, the tactics of Islamic extremists who rely heavily on the Internet, cellphones and satellite television – all of which barely existed in 1980 – show just how much things have changed. Although the basic military systems of the early 21st century look roughly like their predecessors – aircraft, ships and internal combustion machines – what has changed with astonishing rapidity has been the communications, targeting, surveillance and other technologies that have made these legacy systems more potent.

Accelerating Rate of Change - From Web 1.0 to Web 4.0…



In the future, user and programmer alike will be integral participants of what is commonly referred to as the Cognitive Abstraction Layer or CAL. The CAL is a mixture of machine and human intelligence, supported and woven together by new Web 3.0 protocols and technologies, and designed specifically to facilitate problem solving between people acting anonymously in a dynamic cooperative manner. This new paradigm for anonymous cooperative problem solving will set the stage for greatly advancing the current state of our combined technological prowess, raising it to the level needed to begin work on the A.I. supercomputers that will mark the beginning of the "Intelligent Web".

IKC2 – NEW POSSIBILITIES

Premised on the potency that the information age can potentially bring to the military domain, the SAF Integrated Knowledge-based Command and Control (IKC2)[2] concept was conceived to engender transformation in the 3rd Generation SAF.

Four years of IKC2 implementation to realise the 3rd Generation SAF have yielded various insights into what are some new possibilities and alternative models for building up a capability edge. These are based on lessons learned and debated with local and foreign thinkers. The insights presented are not meant to be comprehensive; rather they serve to crystallise current thinking, and to catalyse new thinking and new principles that will emerge over time. Collectively, they underscore the relevance of strategic realities, military capabilities, and enabling technologies for the 3rd Spiral, 3rd Generation SAF.

New Sensing Paradigm

Fundamental to realising pervasive battlespace awareness, as encapsulated in the IKC2 tenet of "Seeing First, Seeing More", is the makeup of the sensor network, in terms of the type and quantity of sensors that are acquired, employed, and fused within the battlespace. In the context of real-time C4ISR operations, many of these platforms are typically high-end, high-cost solutions largely due to the increasing demands we place on such systems. Given the limited resources available, such high-cost implementation inadvertently constrains force-wide proliferation, resulting in viable capabilities being allocated to only upper echelons of command and spot coverage for sensing, connectivity and firepower (hence neither pervasive nor persistent). This mode of operation relies heavily on precise intelligence and demands an accurate knowledge of the complex battlespace.

The value of pervasiveness and persistence is best understood in the context of targeting low signature and Time-Critical-Targets (TCTs). During the July 2006 conflict between Israel and Hezbollah's paramilitary forces, the radical Islamic group adopted an asymmetric strategy of exchanging rocket fire and artillery rounds in battles. In particular, the shorter-range Katyusha or Qassam rockets were easy to deploy and had the ability to reach targets in seconds (average of about 20 seconds), making interception nearly impossible. Even Israel's domination of the air proved ineffective against the crude rockets that Hezbollah used to strike Israeli cities. The Israeli Defence Forces (IDF) was eventually compelled to launch a ground offensive to eradicate the threat. Such low signature targets and TCTs could be circumscribed if an opposing force has a pervasive and persistent sensing capability that allows effective shortening of the "kill-chain".

Small World, Low-Cost Alternative – One way to achieve the desired end-state of pervasiveness and persistence is to develop a massively populated web of ***low-cost*** persistent sensors. In recent years, technical breakthroughs in the fields of nanotechnology and Micro-Electro-Mechanical System (MEMS) technology, coupled with increasing market push (from the automotive and consumer electronics markets) have driven the cost down, making it viable for mass proliferation and employment even in the harsh military environment. These technologies have potentially enormous impact when deployed at a macro scale – particularly small devices laden with sensors. Such emerging trends have found its way into the fields of robotics and Unmanned Aerial Vehicles (UAVs) for operations including sensing. One interesting application would be to overcome some of the dangers that currently exist for ground troops, particularly in urban warfare to carry out the tagging, tracking and location operations.

Israel Looks at the Next Generation of Sensor-Shooter Technology

The war against Hezbollah in Lebanon has convinced Israel of the need to research new ways to fight terrorists. One idea has now received funding – that of building small flying robots that can navigate streets and alleyways.

The "bionic hornet", writes Israel's daily *Yedioth Ahronoth,* could chase, photograph and kill, say, a terrorist hiding with a rocket launcher in a civilian neighborhood – as an alternative to bombing the neighborhood. The Israeli government plans to invest $230 million in nanotechnology research and development (R&D) over the next five years, which would make nanoscience one of Israel's most heavily invested R&D fields.

"The war in Lebanon proved that we need smaller weaponry", said then-Deputy Prime Minister Shimon Peres. "It's illogical to send a plane worth $100 million against a suicidal terrorist. So we are building futuristic weapons."

Source: Deutsche Presse-Agentur

By leveraging on the strength of ***large numbers*** and persistence**,** the resultant capability allows the fundamental paradigm shift from a ***"search mode"*** to a ***"surveillance mode"*** of intelligence/sensing operation. This affords the use of more adaptive planning and dynamic military operations suited for fighting in a non-linear and fluid operating environment. Experiences in Desert Storm, Allied Force, Enduring Freedom and Iraqi Freedom underscore this trend. For example, 20 percent of targets were selected after aircraft launch during the Gulf War, whereas 43 percent were selected once planes were airborne over Kosovo. In Afghanistan, 80 percent of carrier-based sorties were launched without designated targets.

New Cognitive Paradigm

While a pervasive and persistent sensing capability lends promise to having better battlespace situational awareness, it does not presuppose the ability to access all relevant sources of information; far less the ability to lift the Clausewitzian "fog of war". This is particularly true in the fight against small group, insurgency-type forces, as the current situations in Afghanistan and Iraq illustrate. In fact, the ongoing insurgency in

Iraq demonstrates the limited practical value networking one's forces has in obtaining accurate, timely and relevant information on the enemy. An alternative paradigm is needed to gain a better understanding and knowledge of the battlespace.

Newtonian Approach to Warfare – Part of the problem lies in adopting a linear model in our conceptualisation of warfighting; what some military strategists term 'the Newtonian paradigm'. This is characterised by battle outcomes that are deterministically predictable; given knowledge of the initial conditions and having identified the universal "laws" of combat, we should be fully able to resolve the problem and predict the results based on a cause and effect relationship.[3] In other words, Newtonian war is knowable; all the information that describes any situation is ultimately available, and the implications can be fully worked out – that which we cannot directly observe, we will be able to extrapolate.

This leads to a focus on optimisation and war comes to be seen as a one-sided problem to be solved – like an engineering problem or a mathematics problem – rather than an interaction between two highly adaptive forces. This linear approach to warfighting does not account for the fact that war in and of itself is a highly complex event with many unknown variables and interdependencies that are governed by non-linear dynamic properties. Such "frictions" of war are compounded by battle unknowns such as the attrition of men and material, battle fatigue, the loss of morale, poor tactics, uninspired leadership or any other unquantifiable vectors. Indeed, our growing reliance on high-tech systems creates vulnerabilities of its own – future enemies will have strong incentives to attack computer and communications nodes to blind and paralyse us; adversaries will figure out ways to blunt our informational advantage, in a constant competition to gain the upper hand. Technological advances do not change the essential nature of war – it will always be a bloody business subject to change and uncertainty.

But this is not to say that we have no alternatives to managing complexity in war. The key lies firstly in adequately accounting for such interactions; the current paradigm of warfighting in the linear and ordered domain needs to be broadened to include the realities of the complex and chaotic space.

Second and more importantly, we need to put in place a coherent and comprehensive framework to address the varied demands in the unordered domain. The challenge lies in the ability to make sense of the vast sea of data and information, to translate them into a meaningful knowledge repository, so that precise (measured in terms of accuracy and timeliness) decisions and actions can be effected to achieve the desired strategic effects. We believe the answer lies in the ability to create a ***cognitive advantage*** against the enemy.

Since the conceptualisation of the original IKC2 model, the SAF has developed a framework for capturing the different cognitive challenges and solution space to manage complexity. We call this ***Sensemaking*** of the battlespace. As will be discussed later, the SAF ***Sensemaking framework*** brings a new level of understanding to the battle situation, resulting in a greater ability to operate amidst uncertainty and complexity with increased clarity.

Beyond Conventional Decision Support – A key tenet in the IKC2 model also advocates the need for Dominant Battlespace Understanding (DBU), largely premised on development of decision support systems to augment human cognition. Unfortunately, while such systems are ideal for facilitating data and information access/exchange, they have severe limitations in handling complex analysis and relationships.[4]

What is required is a new paradigm in Artificial Intelligence (AI) development that yields the equivalent of human intelligence in machines, making the shift from merely doing ***computer-aided sensemaking*** to the coveted goal of ***sensemaking by computer.***

It has now become clearer that current application of AI technology is unconsciously dominated by the doctrine of imitating "results which a human mind is routinely producing" with the help of computer programs. In other words, programs developed only imitate the output of human intelligence in a brute force fashion instead of modelling the blueprint of human intelligence.[5]

The ultimate goal of AI should be to discover the physical principles behind the blueprint of the human mind and to apply such a discovery to design artificial minds for machines such as humanoid robots, if we want them to exhibit human-like intelligence. In future, we can expect that a machine, which can autonomously develop its mental abilities, will possess a designed mind that enables the machine to sense, to see, to listen, to manipulate entities in the physical world (i.e. behavior) and, most importantly, to manipulate entities in the conceptual world (i.e. intelligence).

Ongoing Efforts on Mining of Human Intelligence

A company called NUMENTA Technology has developed a new computing paradigm that replicates the structural and algorithmic properties of the human neocortex. Known as ***Hierarchical Temporal Memory (HTM)*** technology, it has the potential to allow computers to solve problems that are currently easily solved for humans but difficult or impossible to solve for machines. Examples include a vision system that can recognise faces or a system that can recognise dangerous traffic situations, understand spoken language, recognise and manipulate objects by touch, and navigate in a complex world.

HTMs are unlike traditional programmable computers. With traditional computers, a programmer creates specific programs to solve specific problems. HTM, on the other hand, is best thought of as a memory system. HTMs are not programmed and do not execute different algorithms for different problems. Instead, HTMs "learn" how to solve problems. HTMs are trained by exposing them to sensory data and the capability of the HTM is determined largely by what it has been exposed to.

HTM therefore offers the promise of building machines that approach or exceed human level performance for many cognitive tasks.

New C2 paradigm

The nature of a complex environment precludes the possibility of rigid control with absolute certitude or precision.[6] In the highly complex battlespace environment, many discrete decisions must occur simultaneously at each echelon, and there is little hope that a commander can successfully contend with all of them at the same time. There is also the inherent danger of getting caught in the details leading to distraction from the "larger picture". Caught in this information rut, critical operational decision-making becomes incapacitated. In the end, this leads to belated actions because new and unexpected event information cannot be comprehended fast enough.

At one level, the current concept of "Centralised Control, Decentralised Execution" seems to alleviate these concerns. However, while this is a good alternative to centralised, hierarchical C2 concepts, fully decentralised C2 is unlikely to be adequate for effectively controlling a complex system. Local optimisation may not necessarily lead to a globally acceptable outcome due to unknown higher order emergent behaviours, which are compounded at the global level and add to the overall complexity. Hence "corrective" measures are needed to remedy the overall outcome. The resultant behaviour is analogous to a transient oscillation with a certain damping factor (sensitivity of the feedback loop). Contingent on the overall damping factor, the system converges over time to a final point. This mode of control is reactive and less than precise.

Adaptive C2 – Instead of achieving (or attempting) rigid control, what seems more attainable is an adaptation to the dynamic influences with the goal of preventing resultant regression of command hierarchies into the chaotic space. We believe that the best approach to managing C2 in the complex space is a model that harnesses the best attributes from centralisation and decentralisation, towards a model of ***Adaptive C2.***

Order In Chaos?

Consider a stockbroker in his complex space. Does he control the market movement of the different equities? Does he really even control his own course? The stockbroker, like the warrior, must be constantly aware of the situation and react instinctively and with flexibility to the changing nature of the market. Tying this concept into Command and Control, a group of stockbrokers, when dealing in the dynamic market, will constantly be on the lookout, seeking to understand the dynamics of market trends. As a group, they rely on the buyer's/client's specific intent (maximise profits and user-defined level of acceptable losses) to determine the best course of action or the strategy for gains, relying heavily on real-time market information obtained. However, once they enter the trading floor, the uncertainty principle sets in and each is forced to react to the dynamics of the market based on his knowledge and skill to properly execute the trade at the individual level. This analogy is similar to conflict.

The underlying principle here is that Commanders command with a loose rein by influencing the system parameters and ***boundary conditions***, allowing lower command echelons greater freedom of action and requiring them to adapt locally to developing conditions. Subordinates are therefore guided not by detailed instructions and control measures but by their understanding of the requirements of the overall mission. An instantiation of this approach can be seen in an SAF experimental prototype, called ***"ONE-Control"***.

ONE-Control **– An Example of Adaptive C2**

In *ONE-Control*, commanders will directly control systemic effects at the higher level to guide decentralised, autonomous decision-making at the local level. It is believed that this mode of C2 will be more effective as it abstracts away the underlying complexity of the network, leaving commanders to focus on the outcome of force employment rather than its mechanics.

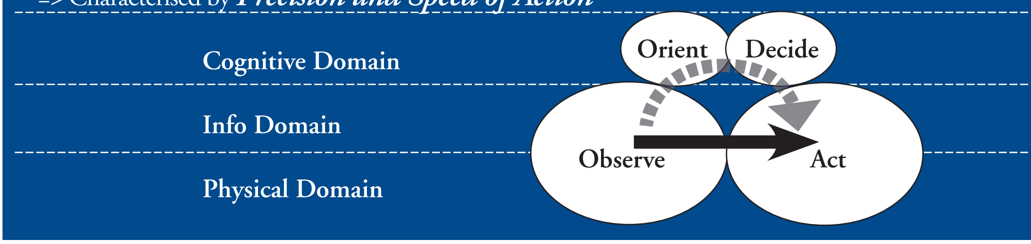
Under *ONE-Control*, it is envisioned that commanders will view and adjust high-level systemic effects directly (e.g. bandwidth over an AO). Prior to the execution of a decision, the commanders will be able to "preview" the effect their decisions will have on other functional commanders. Following execution of a decision, feedback from the battlefield, such as the impact of attrition, will be similarly displayed as effects for the commanders' appreciation. Conceptually, this will give the commander greater awareness of, and allow him to better focus and comprehend, the operational impact of his force employment decisions. Technically, this will be achieved by the development of a visualisation tool to enable commanders to view effects rather than unit positions, and a Decision Support System that will interpret effects and feedback from the battlefield for the commanders' appreciation, and translate high-level effects-based commands as required for subsequent execution by downstream units.

Reducing C2 Complexity by Fighting in the Known/Knowable Space – Part of the thinking behind the new C2 paradigm also involves adopting a different mental orientation of how an operational problem should be defined. By re-scoping the complex problem space, we effectively redefine the "focal points" of the problem and allow the shift from the unordered into the ordered domain, where simpler rules and complementing solutions can then be applied. An instantiation of this model of C2 is in targeting operations. By re-scoping the problem space with clear rules of engagement, any detected targets can be eliminated without the need for further sensemaking. This effectively enables a shorter C2 cycle loop, enabling the ability to Observe and Act.

IKC2 in the Known/Knowable Space

Reducing complexities into the known/knowable space allows for:

- Ability to minimise the demands on situation orientation and decision-making
- Problem space is now reduced to seeing and acting based on simple rules
- => This leads to the ability to ***Observe then Act***
- => Characterised by ***Precision and Speed of Action***



Re-scoping a Problem Space: Example of the IED "Value Chain"

From analysis of the Improvised Explosive Device (IED) attacks in Iraq, the complex space of countering IED can be re-scoped to make the shift from the unordered to ordered domain. This is done by analysing the IED value chain. At the top of the chain, it is difficult to contain or control the supplies of illegal explosive given the accessibility of supply both within and across the border; attempts to control this would be resource intensive and non-scalable. Efforts at component forensics of exploded ordinances will also have limited success and tedious given the use of many home-made components. In the execution stage, the ease of which the insurgents can blend in with the crowd makes it difficult and untimely to detect him. Hence, the highest point of vulnerability for any IED attack is at the point of physical deployment, particularly for large IEDs. By tackling the problem at this vulnerability point, the level of complexity has been significantly reduced and a much simpler rule set or solution can be effectively applied.

IMPLICATIONS FOR THE 3RD SPIRAL

The possibilities and potential that exist for the 3rd Spiral, 3rd Generation SAF are tremendous and the examples cited provide only a glimpse of what is possible. Many of these disruptive effects will require us to organise ourselves differently and reshape our investments for the future. We believe that the prevalent trends point towards ***three key implications*** that will increasingly influence our implementation of IKC2 in the 3rd spiral:

Dealing with Change, Uncertainty and Complexity

David and Alex Bennet posited in their book "Organisational Survival in the New World" that the new landscape of the world we live in can be described at the highest level by three emerging characteristics: ***accelerating change, rising uncertainty and increasing complexity.***

This aptly describes the key challenges that beset the transformational efforts of the 3rd Generation SAF. The speed and quantity of data, information and knowledge will force us to develop new systems and human capabilities that can adequately respond to such an environment. It will compel us to learn how to learn, create, leverage and apply knowledge faster than the environment can change.

Specific to the IKC2 implementation, SAF investments in Sensemaking are showing signs of valuable payoffs. Though still early in its formulation, this multidimensional approach has based its research on fundamentals pertinent to Complex Adaptive Systems (CAS). Our efforts in this area of development will be pivotal in unleashing the true potential behind IKC2.

Dealing with the Effects of Large Numbers

The 3rd Generation SAF's sensing, connectivity and firepower systems will need to expand significantly to fully realise its transformational potential. The wider proliferation of the desired warfighting characteristics is necessary across the entire system and not just as a small baseline capability.

Given this envisaged expansion, the complexity of the network will increase exponentially.[7] There will be emergent behaviours (*à la* the Internet experience) and even new undiscovered capabilities. The combination of its size, rapid growth and decentralisation will pose tremendous challenges to understanding its behaviour, before we can hope to control it.

As the 3rd Generation SAF networks continue to grow on this revolutionary path, it is important to study the effects that large network and increased connectivity will bring to the operational domain.

Dealing with Growing Relevance and Dependence on COTS/MOTS

Commercial Information Communication Technology (ICT) has demonstrated that it is possible to affordably deliver pervasive broadband networking to the ground. This will have a profound impact on C2 and our ability to harness knowledge in creating a cognitive edge at all levels of warfighting; from developing options for networks to developing sensemaking solutions.

Emerging commercial design paradigms applied to tried and tested technologies have made capable low cost platforms a reality. The declining cost of such Commercial-Off-The-Shelf/Modified-/Modifiable-Off-The-Shelf (COTS/MOTS) solution will potentially allows a disruptive proliferation of key capabilities even for traditionally high-cost capability areas.

Implicitly, the 3rd spiral development strategy will need to embrace the use of COTS/MOTS in an unprecedented way. This will increasingly become an operational imperative for the SAF to realise its force-wide transformational objectives.

CONCLUSION

The effective application of these paradigms and principles as outlined can be applied on a broader scale across the entire system. The following discourse in the remaining part of this section will expound further on the three key implications and provide further clarity on the unfolding of the 3rd spiral development.

3 DEALING WITH CHANGE, UNCERTAINTY AND COMPLEXITY

SENSEMAKING IN THE COGNITIVE REALM

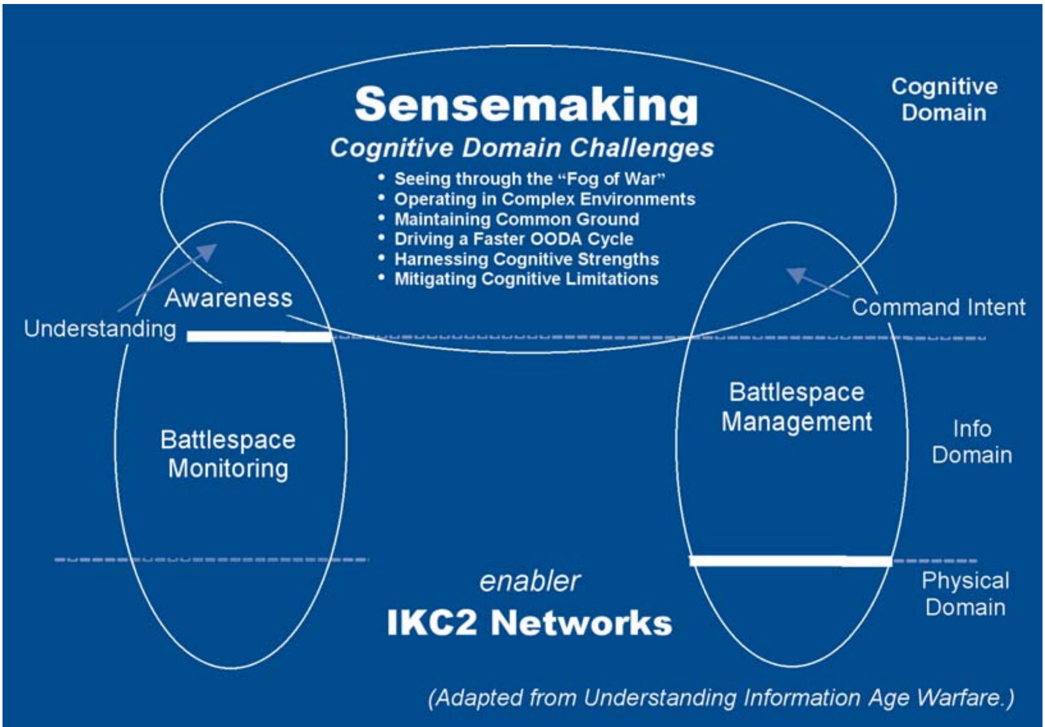
Operational commanders face challenges in making sense of situations characterised by rapid change and high levels of uncertainty, in which diverse assumptions and perspectives are held among participants acting on imperfect information. Under such conditions, situational awareness is crucial but typically difficult to attain in a timely manner, and even harder to achieve with coherency among different parts of an organisation, let alone across different organisations. Since the time of Clausewitz, the military has known this state of affairs as the *fog of war.*

In recent years, networks coupled with advances in sensor technology, offer possibilities for lifting the fog of war in ways that are unprecedented in history. With better sensors and networks, the expectation is that there will be more information, and more information should lead to better situational awareness. In this article, we argue however that networks and information alone will not be enough. **To fully realise the potential of networks and the information revolution, we will need to leverage on the cognitive realm and sensemaking.**

We discuss key challenges that sensemaking needs to address and sketch the ongoing work at the Future Systems Directorate aimed at developing solutions for these challenges. We will explain how, in our view, the challenges are fundamentally cognitive in nature and as such they cannot be resolved simply through physical network connectivity or the availability of information. Rather, a deeper understanding of the underlying cognitive, psychological and sociological processes is required. Nevertheless, we believe that overcoming the challenges will help deliver a **sustainable warfighting advantage** for the SAF – we call this advantage a **Cognitive Edge.**

SENSEMAKING CHALLENGES

The promise for IKC2 to transform warfighting is summarised in the figure. Networks are key enablers for this transformation leading to improvements in battlespace monitoring. With better battlespace awareness, sensemaking is needed to produce the deep understanding[8] required for superior decision-making and battlespace management.



IKC2 Networks and Sensemaking Challenges

Here, we identify six key challenges that the process of sensemaking must address.

Seeing Through the "Fog of War". The first challenge for sensemaking is overcoming the proverbial "fog of war" referenced earlier. This "fog" is often generated by the lack of data, but in today's environment it can also be due to an inability to make sense of overwhelming amounts of data. With advancements in networking and information technology, the latter problem is in fact compounded. The challenges here include getting to the data, detecting the important data quickly among the mass of other data, and connecting the dots to find patterns that will illuminate the situation-at-hand. Access to data itself can be a problem because bureaucratic structures sometimes encourage protectionist behaviours, resulting in people hoarding information, or the structures themselves might hinder information sharing because of information stove-piping. This was illustrated by events during the terrorist attacks on September 11, 2001, where information was "out there" as the situation unfolded but could not be effectively shared and exploited. So, an important challenge for sensemaking remains in enabling *access* to and the *sharing* of the massive amounts of data from different places in the organisation, and then to *exploit* them by finding useful patterns in the data.

September 11 – Complexity and Confusion

September 11, 2001. At 0937hrs, hijacked American Airlines flight 77 had crashed into the Pentagon in Washington DC. Minutes earlier, two other hijacked flights – American Airlines flight 11 and United Airlines flight 175 – had crashed into the World Trade Centre in New York. There were further reports of hijacked aircraft headed for the capital, but many of these would later turn out to be erroneous. The situation was developing very rapidly and information was fragmented across multiple agencies and multiple levels of authority in the US civil and military bureaucracy. A decision to shoot down hijacked commercial aircraft was required quickly to safeguard against further threat of such aircraft being used as weapons. This was thought to have been decided between the President, who was then in Florida, and the VP in an open line conversation sometime between 1000hrs and 1014hrs. The decision however was not passed on to the operational levels because the sector commander was *"unaware of its ramifications"*. As a result, aircraft from Langley AFB over Washington DC under the command of the Northeast Air Defence Sector remained on "weapons tight". On the other hand, another set of fighters launched by the Air National Guard from Andrews AFB were given "weapons free" orders by way of information going directly from the White House, through the Secret Service, to the Andrews AFB commander, bypassing the NORAD chain-of-command! At 1039hrs, the VP was heard saying on the Air Threat Conference that the shoot down instructions had been conveyed to the fighters under NORAD command and "It's my understanding that they've already taken a couple of aircraft out", to which the Secretary of Defence responded "We can't confirm that. We're told that one aircraft is down but we don't have a pilot report that did it". It later became apparent that the one remaining hijacked aircraft United flight 93 had indeed been taken down, but not by the air force but by the heroic actions of passengers onboard.

Source: 9/11 Report

Besides dealing with problems caused by sheer volume of information, there are cognitive challenges that make sensemaking difficult. One challenge has to do with inadvertent *filtering* of information as it passes through people and organisations. These filters are formed by the mental models of people, which in turn are the products of organisational worldviews, individual biases, and sometimes group biases (e.g. resulting from dominating personalities). As the famous example of Yom Kippur showed, the data might sometimes be obvious except that people can be "blinded" by their preconceptions. At other times, the problem is one of "weak signal detection"; that of having to look below the noise level for the important data that might otherwise be filtered out.

Yom Kippur – Not the Data's Fault

IKC2 promises that soldiers "See More, See First". Will the ready availability of information made possible by networks and sensing guarantee success? What happened in the Yom Kippur War in Oct 1973 showed that making the right decisions involved more than just "getting the data".

Prior to the onset of war, the Egyptians and Syrians did things that should have raised the alert for war, such as bringing in SCUD missiles from Russia, taking in batteries of SAM surface-to-air missiles and conducting massive mobilisation of forces on the pretext of training. Israeli Defence Forces (IDF) intelligence assessment discounted these signals because of a longstanding preconception about the Egyptian Armed Forces – that the Egyptians would never go to war unless its own air force was capable of taking on the IDF formidable Air Force with medium range bombers and fighter-bombers. Such a capability was being built up by the Egyptians and was estimated to be available only in 1975. The IDF did not expect that the Egyptians would conceive a new strategy using air defence weapons to counter the IDF Air Force. In this case, data was available that should have suggested impending war but they were either ignored or interpreted wrongly. Mental models, which are "cognitive" constructs, and not the data, prevented the right conclusions from being made.

Source: The Arab-Israeli Wars

Operating in Complex Environments. Even if we can be all seeing and succeed in overcoming the problems of information overload and weak signals, there is another aspect of the fog of war that presents another challenge to sensemaking. This has to do with *complexity*[9], which is an inherent characteristic of the military environment. It arises from the interaction of multiple entities (own, adversarial and neutral) that produce emergent phenomena which are difficult to predict. Under such conditions, causality is non-linear and often only discernible retrospectively. New approaches for managing complexity are therefore required that are different from the linear planning methodologies militaries traditionally use. Crucially, these new approaches must provide the capacity, both mental and physical, for us to be adaptive to change, so as to be able to exploit opportunities and to mitigate problems as they emerge. These include the ability to detect opportunities and problems, react swiftly to them, and even to switch to new response structures where appropriate, while poised all the time to maintain the capacity to change. These are non-trivial demands given that military and government organisations have traditionally been built for order and efficiency, and inherently lack the required complexity orientation. Such organisations are optimised for environments that are known and for situations whose course is predictable – for which a formal and rigid system of roles and actions work well. Against complex dynamic environments, we need structures that are built for adaptability as a response rather than predictability. In the example of September

11, a different approach to handling hijacking was needed because the hijackers were not interested in using the hijacked aircraft as bargaining chips. But the rigid mindsets and processes of the parties involved from across the US government prevented a sufficiently adaptive response to avert disaster.

Maintaining Common Ground. A third sensemaking challenge is that of maintaining common ground across the organisation. We define "common ground" as a state of *sufficient agreement and understanding* established across a group of people with respect to the situation and the commander's intent that will permit unity of action and self-synchronisation of independently operating units. Common ground is a prerequisite for coordinated response to dynamic situations, and can make the difference between shooting the right targets and fratricide. As with the earlier identified challenges, attaining common ground is not guaranteed by connectivity and networks. Achieving common ground is not easy in practice due to several reasons. First, organisations are generally made of people with different and diverse mental models due to their varied cultures and experiences. Their different perspectives present significant impediment to achieving a common appreciation of the situation. Second, communications between people and different parts of organisations, necessary for levelling-up the knowledge for creating common ground, tends to be imperfect. In a chicken-or-egg kind of way, communications can be ambiguous, and often rely on common understanding to "fill in the blanks". So, when latent prejudices or understanding based on different assumptions underpin communications, the result could be communications losses or misunderstandings that might further erode common ground. Third, as we pointed out before, bureaucratic organisations tend to compartmentalise knowledge and encourage protectionist behaviours, and because people refuse to share their information, problems in forging common ground are exacerbated. Again, the events of September 11 serve to illustrate the point – the lack of common ground between NORAD and the US executive leadership potentially exposed the nation to further suicide attacks even after the latter had taken the decision to shoot down subsequent hijacked aircraft.

Driving a Faster OODA (Observe-Orient-Decide-Act) Cycle. One of the key operational goals of sensemaking is to deliver an increased speed of command, or in the parlance of John Boyd, to increase the rate of traversing the OODA loop, and in the process "create time". The aim is to do so not just quicker but also much more effectively than the adversary, and possibly calls for new structures and processes for faster decision-making and better battle management. However, it is clear that the understanding and decision-making activities that drive the OODA cycle are seated firmly in the cognitive domain. We therefore believe that the heart of the problem lies in the cognitive, psychological and social realms, and progress towards a faster speed of command is not attainable just by "business process re-engineering". Faster OODA stems from faster sensemaking, which in turn hinges on our ability to conduct a range of cognitive, psychological and social processes faster including assimilating information, understanding the situation, communicating, problem solving and decision-making. One example of leveraging on our innate cognitive abilities to give us a speed advantage is to exploit our innate ability to recognise complex patterns – an ability that we believe underlies human intuition.

When the Lack of Data saved the Day

Sensemaking needs to exploit our innate cognitive abilities, including our amazing human ability to recognise sensory cues and patterns from experience. A key to fast-OODA decision-making lies in the "guts" – the intuition – of the decision maker.

A group of firemen led by a Lieutenant were fighting a fire at the back of a house. When they sprayed water at the fire, the flames would roar straight back at them. This occurred time and again as they continued to try to subdue the fire. Finding the situation atypical, the Lieutenant decided to pull his men out from the house. Soon after, the floor at the back of the house where they had been standing collapsed. Had the firemen still been standing there, they would have plunged into the fire below. The Lieutenant had made a life-saving decision based not on data (because the "right" data was missing) but on his "guts". In fact, not having the data helped him make the correct decision as his expectations were violated. Had he relied on rational thinking, he would have been paralysed into inaction by the lack of data.

Source: Gary Klein, Sources of Power

Harnessing Cognitive Strengths. Enlarging on the idea of leveraging innate human cognitive abilities, another key challenge for sensemaking is to harness our cognitive strengths. These include reasoning, pattern recognition, intuition, creativity and learning. The challenge is to enable people to perform these functions better and faster.

The Power of Creativity

We are often amazed by human ingenuity, our ability to do the unexpected and the extraordinary. People have this ability to improvise and devise new procedures using knowledge and flashes of genius.

Apollo 13 – Jury Rigged Live Support System: One of the major problems onboard the Apollo 13 flight was the accumulation of carbon dioxide (CO_2) within the ship's atmosphere. To solve this problem, members of the earth-based Manned Spacecraft Centre (MSC) had to devise a makeshift air purifier using only material available within the spacecraft. They used lithium hydroxide canisters (CO_2 scrubbers that chemically remove CO_2 from the air), plastic bags, cardboard and tape to create a device that could be attached to the crew's life support system. After testing that this jury rig would work, they sent the instructions to the crew, who put together the device like lego. The device worked well throughout the rest of the mission.

Finding the Breathing Passage. A doctor had to intubate a baby – insert a slender tube down his throat – in order to create a breathing passage. He had an inspiration from an earlier case when he had to treat a young man who had barbed wire entangled around his throat. In that case, the young man already had a breathing tube inserted into his lungs by an emergency technician when he arrived. The doctor wondered how this was done since it was not easy to find where the breathing passage was when it had collapsed. The emergency technician explained that he had stuck the tube where he saw bubbles since bubbles meant air coming out. It worked. The doctor decided to apply the same technique on the baby. When he was not able to see bubbles through the baby's throat, he pressed the infant's chest to force the last bit of air from his lungs. When the bubbles emerged, he was able to slide the tube inside.

Sources: Apollo 13 resources from the Internet (e.g. Wikepedia and NASA sites) and Sources of Power by Gary Klein.

Mitigating Cognitive Limitations. Finally, we recognise that just as the human cognitive system has its innate strengths, it also has weaknesses. Sensemaking must therefore seek to mitigate these weaknesses. For example, the human cognitive system has well-known capacity constraints which include limited attention and memory spans that affect our rate of information uptake, as well as our ability to remain vigilant over prolonged periods of time. Our memory is also not as reliable as we are given to believe. This refers not only to our ability to maintain items in memory across time but also the veracity of the recalled memories. Psychology tells us that human recall is different from data retrieval in computers. The latter involves a direct read-out of the contents previously stored at a memory location, whereas normal humans recall events through a process of pattern completion, reconstructing them using partial cues offered by the environment on the basis of their mental models. This makes human recall susceptible to the phenomenon of false memories, particularly when cues are ambiguous or when strong biases colour the encoding or reconstructive process. Biases may also affect the way information is perceived and stored in the first place. While these properties of the human cognitive systems might be adaptive from an evolutionary perspective, they invariably impact the efficiency and effectiveness of human information processing and the quality of decision-making when cold hard sensemaking is required. On top of that, physical and affective influences such as stress, hunger, fatigue and fear may potentially compound the effects of our cognitive limitations and further degrade our sensemaking performance.

REALISING THE COGNITIVE EDGE

At the Future Systems Directorate, the six sensemaking challenges discussed above have motivated separate programmatic responses to develop solutions which together address the underlying cognitive issues that have been identified. We describe these in the remainder of this article.

Cognitive Precision. Cognitive precision is about *getting the data right*. Achieving it will help reduce the "fog of war" by eliminating errors due to biased filtering of the data. A solution set that we refer to as *Enhanced Reasoning Techniques* (ERTs) aims to enhance a person or a team's powers of reasoning by systematically increasing their "scanning range" and preventing premature mental "lock-in". ERTs comprise interventions that encourage people to explore multiple perspectives in order to mitigate fixation. For example, one of the interventions is based on Popper's "*Hypothesis Falsification*" methodology. The technique's first step is to detail a list of possible conjectures after which a rigorous process of hypothesis testing is carried out to eliminate conjectures based on available data. This technique, by design, encourages the exploration of multiple possibilities. Another initiative is a "machine-based" approach called the *Massive Sensemaker*. The idea is based on the premise that machines are unbiased in their treatment of data and exploits the ability of machines to deal with massive amounts of data. The Massive Sensemaker project will develop a system that will exploit state-of-the-art data mining technologies to automatically perform large-scale data crunching, and analytics to detect interesting patterns from bottom-up, and to raise alerts to well-understood patterns of interest.

Focus on "Massive Sensemaking"

Human mental models affect cognitive precision. Machines on the other hand, are not affected by emotions and "historical baggage". The idea behind the Massive Sensemaker is to exploit computing power to crunch large amounts of data to surface patterns in data that are invisible to the naked eye, the proverbial needle in the haystack.

The work needed to get to the point where patterns can be automatically detected is onerous. Data needs to be prepared – decomposed, cleaned and normalised – hence, a precursor to the Massive Sensemaker is a "Data Factory". FSD is currently developing a system to break data down to its basic cognitively relevant building blocks – entities and events – to be ready for the next steps involving "data resolution" and "data networking". Jeff Jonas has famously described the goal of the process as "data finding data and relevance finding users".

Adaptivity. Adaptivity is a response necessitated by complexity. Adaptivity allows individuals and teams to be sensitive to change, embrace them, and adopt the right stance for dealing with change. The desired outcome is the capacity to exploit opportunities that emerge and to take early action to mitigate problems. FSD's programme deals with adaptivity at the cognitive, physical and system levels. At the cognitive level, people need the mental agility to see problems early and to shift perspectives in anticipation of the demands of the situation. Mental agility is helped by being adept at "looking-ahead". One suite of capabilities that is being developed to facilitate *Anticipatory Thinking* includes mechanisms for detecting emerging problems, and for probing and stimulating responses from complex environments. At the physical level, the key capability needed is to enable a commander to convert his adapted plans into actions as dynamically as possible. Processes, structures and the roles of people may need to be changed on-the-fly. *On-the-Fly* is a set of technologies and techniques that enable adaptive organisations complemented by adaptive C4ISR systems which self-organise and reconfigure to the demands of the users and the operating environment.

Focus on "Anticipatory Thinking"

Anticipatory thinking is an *active* stance to thinking that we believe is essential for "cognitive agility". To be better at switching between different "states of mind" (mental models), we need to be mentally primed and prepared. Anticipatory thinking is a set of mechanisms that prepares our mind for what is ahead.

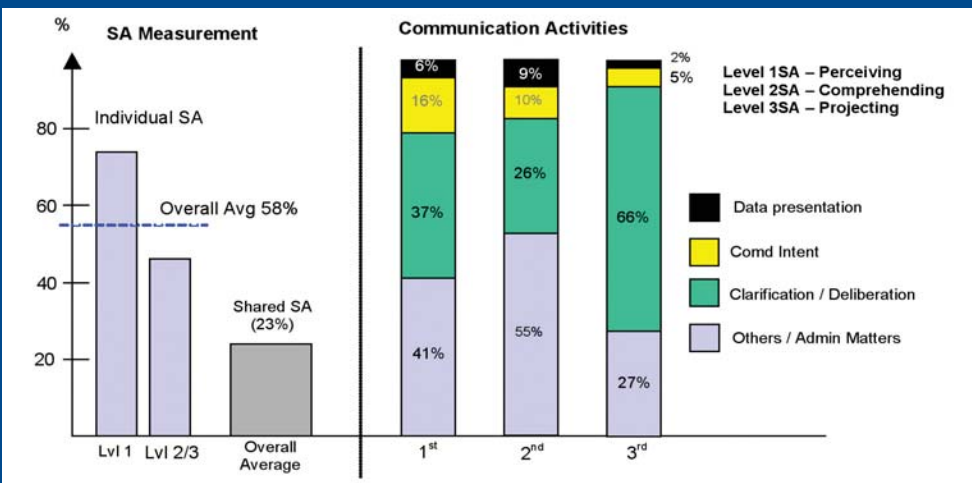
Anticipatory thinking is not "retrospective sensemaking", which aims to understand the past to prepare for the future. It is also not "prediction", which tries to foretell future events. Rather, it is an active process to facilitate looking ahead and preparing for the future.

There are 3 types of Anticipatory Thinking – (1) *pattern matching* is a mechanism for applying past solutions to new situations; (2) *trajectory* is a technique for anticipating future events by extrapolating from trends; and (3) *conditional* is a process of looking at connections between events to consider the interdependencies between them and assessing their outcomes.

As One. The 3rd Generation SAF will be leaner and meaner, seeking to exploit networks for new ways of fighting. One of these new fighting approaches is likely to involve many more smaller interdependent units working in parallel and self-synchronising to deal with the complex operational environment. *See and Operate As One* is a sensemaking programme aimed at creating a set of capabilities that help large decentralised organisations achieve better common ground and unity of effort. This includes a suite of C2 systems that help people achieve good common understanding of the situation and each other's intentions. *In Parallel* is an effort directed at making working collaboratively easier. This involves dealing with people-to-people issues such as building trust, improving efficiencies of coordination and reducing the cost of communications. The programme is developing tools such as data management and information sharing systems that help people organise themselves, and asynchronous or synchronous rich communications tools to reduce the need for face-to-face meetings. If people are able to work as one efficiently, time is "created". The additional time represents extra capacity for sensemaking and adaptivity.

"See and Operate As One"

One of the most difficult challenges faced by teams working together is in building "common ground". An experiment during a command post exercise in 2003 by *Cheah et al* illustrates this point. The graph on the left below shows that while individual situational awareness (measured using a SAGAT survey) was good (~80%), the shared situational awareness of the command team scored much worse (~20%). The next level of details (graph on the right below) illuminates what goes on between people. A large amount of time was spent on overheads such as administrative tasks and data presentation (~50%), and for clarification and deliberation (~40%), leaving little time on "command intent" activities. The time spent on clarification is interesting – it reveals that a lot of effort actually went into learning what others in the organisation know, to develop common ground, but only with moderate success. This data also shows that there is great potential for better C2 and collaboration tools to reduce the effort involved in administration and information sharing. One of our projects is a C2 system called "Mission Mate" that allows teams to share their plans in a collaborative, white-boarding manner – by exposing and making explicit their mental models common ground can be developed. Another project called the "Information Broker" aims to standardise the "data-scape" and hence reduce differences at the level of the data by building a system that pulls data from across the organisation to normalise them. Another key function of the "Information Broker" is to create clear identification between "facts" and "derived data" (outcome of reasoning from facts). The latter two are often the source of confusion and the cause for lengthy clarification processes.



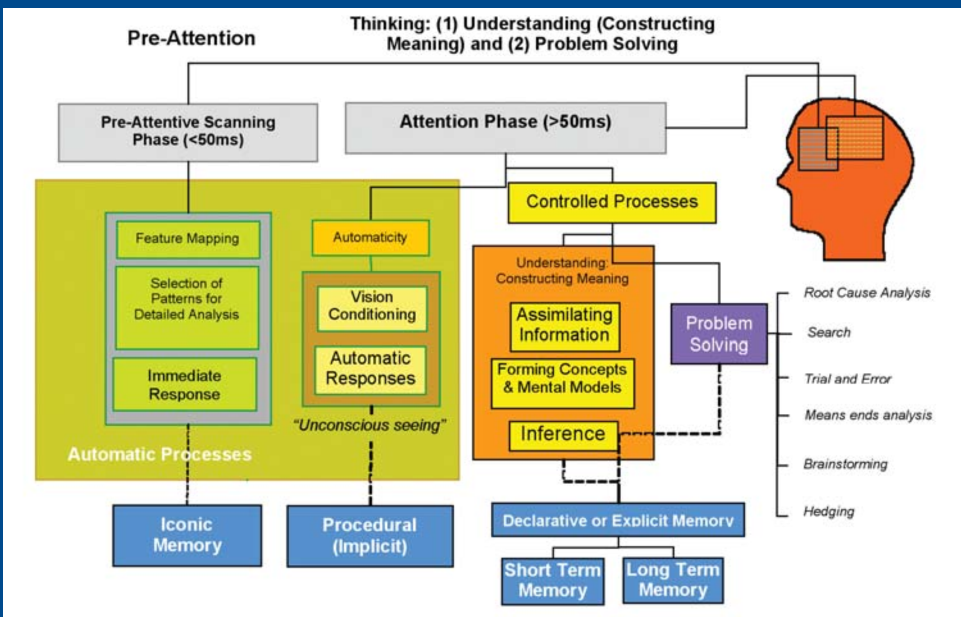
Data on Situation Awareness in a Command Post.

Rapid Cognition. Rapid Cognition is about fast and accurate assimilation of information by individuals. Faster cognition will lead naturally to faster OODA cycles. To find solutions to increase the rate of information ingestion or exchange, we identified two cognitive processes involved in these tasks for enhancement. The first deals with how an individual ingests information from the sensory world into his mind. The *One Glance* project deals with this problem. The second process deals with cognition involved in information sharing and exchange among people in a team. The goal of the *Short and Sharp* project is to enable people to confer with each other with high precision and throughput, but with minimum exchange.

"One Glance Schematics"

How can we achieve rapid cognition? How do we see? What can we do to improve the rate of information assimilation? Can we improve visualisation to achieve a "one glance" information uptake?

When trying to answer these questions, we discovered that "seeing" as a cognitive process does not occur independently of other aspects of cognition. In fact, "seeing" is intimately linked to "thinking". The work of the psychologist Bartlett (1932) ("Schema Theory") illustrates this. Bartlett studied how people assimilate information and concluded that it is determined very much by the "schema" or "mental model" of a person. Bartlett pointed out that people either "level" information, i.e. ignore data that does not fit his schema or "sharpen" them, i.e. choose data that support their mental models. In other words, if information presented is not in line with one's schema, it will be useless.



SEAT – A Model of Seeing

Given this understanding, we mapped out cognitive psychological processes from literature linked to "Seeing": Firstly, Pre-Attentive Scanning (left hand column) is "unconscious seeing" built-in to our physiology. It responds to visual stimuli such as motion or color usually pertinent to our survival, e.g. motion may be linked to incoming threats. The second column, Automaticity, refers to "automatic processes" learnt through repetitive training e.g. driving. The third column refers to the conscious activity of "thinking". Here, is where the deliberate processes of "understanding" to "problem solving" take place. We discovered that each column requires different solution strategies:

Pre-Attentive Scanning: Improvements to visualisation are achieved by careful application of **"gestalt principles"** pertaining to the use of features such as colour, shape and motion.

Automaticity: If the domain is well-structured and well-understood, such as Air Defence Operations, the strategy is to use **Decision-Centred Methodologies** (e.g. Cognitive Task Analysis) to elicit from experts key decision-making cues. Once established, rapid cognition will be achieved by repetitive training – honing of visualisation and processes based on these cues.

Controlled Processes: The process of thinking is fluid and changes from time to time. To create structure in the midst of dynamism, the idea of **"Thinking Schematics"** was developed. "Thinking Schematics" are templates of thinking (from understanding to problem solving) with their associated set of component processes and visualisation, devised to synchronise visualisation with the thinking processes. The insight is that different problem types result in different processes, thus we expect different visualisation schematics for each of them. For example, the schematic for "Resource Management" is different from "Operations Planning" (a Means-Ends Analysis process). For the former, the staff looks at resource commitment, availability, demand priorities, and allocation, which are best visualised using graphs and tables. For the latter, the staff looks at enemy deployments, own force deployments, force plans, and contingencies, which are best visualised with maps. To assist in such controlled processes, we plan to develop sets of widgets, which are task-sized human-computer interface applications to support each schematic.

Reliable Instincts. This programme looks at developing the natural cognitive strengths of SAF soldiers, particularly their innate ability to make very good decisions without complete information; i.e. with their "guts". Human decision-making studies by cognitive psychologists such as Gary Klein suggest that the process is not purely a rational one. In many situations, experienced commanders rely on intuition and are found to be just as effective, if not more effective. The studies also show that the quality of intuition is linked to the level of expertise, i.e. experience and knowledge of the person. Projects in this programme are aimed at further developing correct instincts in our commanders. The programme is modelled after state-of-the-art techniques (such as cognitive tasks analysis) developed by cognitive psychologists to elicit key decision-making cues, and modelling of expert-novice mental model structures to determine the underlying foundation of their intuition. We hope to then develop new training interventions (pedagogy or system-based training), C2 techniques and software systems that improve or aid intuitive decision-making.

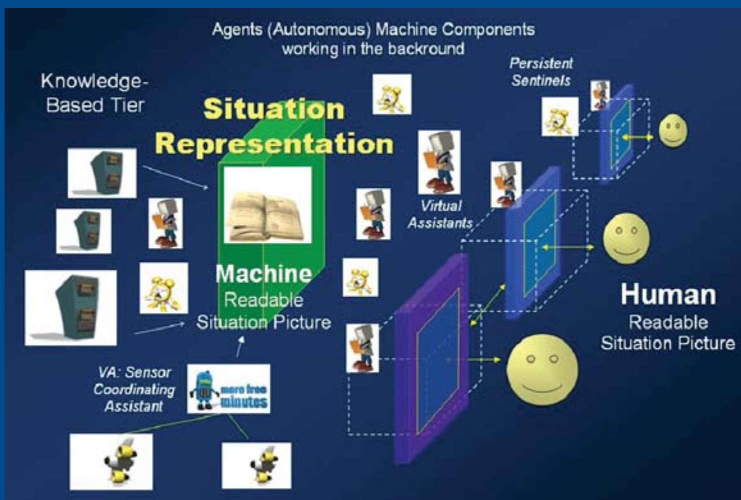
<u>"Instant Experts!": Techniques to Turn Novices into Experts.</u>

In recent years, a great deal of research has pointed to intuition playing a big part in decision-making. We are beginning to understand how to hone or cultivate "guts". One of the projects developed by FSD and DSTA is based on the work by renowned Cognitive Psychologist Gary Klein. Klein was the originator of the notion of "Recognition-Primed Decision Making" (RPDM), which argues that the experts would match an approximate "pattern" from his past experience to his current reality and use this pattern to guide his future actions. His work further suggests that people would find it hard to make explicit his "expertise", but the imparting of the expertise could be achieved by having the expert nurture the novice over multiple realistic scenarios. With this theory, we conceptualised and developed a system to facilitate expert imparting knowledge to novices. This system allows both of them to externalise their "schema" or "thought processes" and by comparing and discussing over their differences, this would enable the expert to instil in the mind of the novice the "critical cues" he has used in the decision-making.

<u>Augmented Cognition.</u> Augmented cognition is about mitigating our cognitive weaknesses, and enhancing and amplifying our cognitive faculties so that we can perform *beyond* our cognitive capacities. Cognitive areas that could be mitigated are overall cognitive loading, attention, visual-perception resources and working memory. *Social-Networks-On-the-Fly* is a project to create networks of people so that they could leverage on each other for their knowledge and expertise to solve a range of problems. *Virtual Assistants* are software agents that offload the commander of mundane tasks and enable him to concentrate on more cognitively challenging tasks such as problem solving. *Persistent Sentinels* are software robots that help the commander with his limited attention span to remain vigilant over critical operational tasks, particularly ones that involve prolonged monitoring. Finally, *Human-Computer Symbiosis* is an attempt at creating a closed-loop human-computer interdependent system that adapts the computer to the different cognitive states of a person to achieve optimal performance.

"Virtual Assistants and Persistent Sentinels (VAPS)"

The purpose of Virtual Assistants and Persistent Sentinels (VAPS) is to mitigate the limitations of human cognitive capacities; in other words, to augment cognition. In one of our projects, we first construct a machine-readable "situation representation" underneath the situation picture for humans. With the machine-readable representation, software robots – the VAPS – can then exploit the information for machine-machine collaboration and to carry out tasks on behalf of humans. Most of these will be simple tasks such as "alerting", "data proliferation", "options presentation", and "coordination management". VAPS could ultimately facilitate a revolution in C2 paradigm from *human-direction* to *human-veto*, offloading most of the cognitive demands from the human.



Virtual Assistants and Persistent Sentinels

CONCLUSION

We believe that sensemaking can give the SAF a "**Cognitive Edge**". Our cognitive edge will be derived from our ability to bring to bear the sum of the cognitive resources at our disposal, through systems, processes and structures that exploit the cognitive strengths of individuals and teams, while mitigating our weaknesses. FSD's sensemaking solutions described in this article have been developed from first principles through an analysis of the cognitive, psychological and social bases of sensemaking. They are aimed at overcoming key challenges to sensemaking and will be validated and refined through further experimentation.

4 DEALING WITH THE EFFECTS OF LARGE NUMBERS

CO-EVOLUTION OF MILITARY OPERATIONS, COMMAND, AND CONTROL

Warfare is complex and increasingly so. Military operations and the environment in which they are conducted exhibit greater system interdependency and sensitivity. Military operations are more likely to exhibit larger perturbations, non-linear characteristics and catastrophic failures. The traditional engineering-style control theory approach to conducting military operations is not scalable and unable to meet such challenges. On the other hand, insights from network sciences and complex systems could infuse intelligence and adaptivity to "control" complex systems such as the military operations.

The issue of command and control of operations in conflicts relates to four areas – nature of conflicts, the environment in which conflicts occur, the essences of command, and control. None of these can be considered in isolation as they are intimately intertwined and have co-evolved throughout human history. While conflict is ultimately an "act of violence intended to compel our opponent to fulfill our will"[10], the nature of conflicts have evolved from small raiding parties during the Stone Age, to the chivalric and honorific order of knights of the middle ages, to Carl Von Clausewitz's absolute war, to the cold war era, to the present day war on terror and possible unrestricted war (warfare beyond bounds).

> The spectrum of conflict is no longer (if it ever was) a neat, easily comprehended linear escalator – with peace at one end and war at the other – it is a continuum within which lies a range of military and non-military conflict prevention, conflict and post-conflict activities. The distinction between these is blurred and it is possible to conduct all three forms of operation simultaneously in the same theatre of operations. Such a view is coherent with Krulak's vision of the 3-block war – in which we find humanitarian, peace keeping and warfighting operations being conducted at the same time and in space of three city blocks.
>
> *Source: David Potts, The Big Issue*

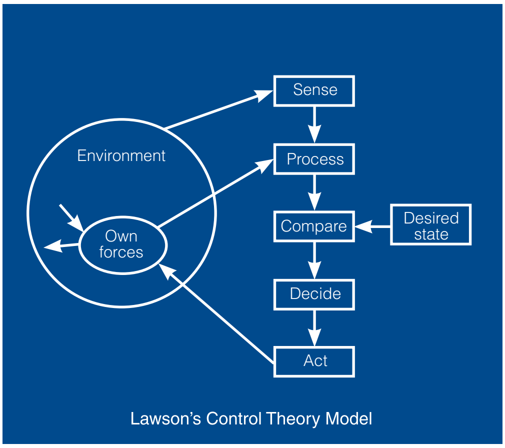
The changing facade of conflicts, their causes, styles, morality, scale and ending conditions demand different strategies, force compositions, training and doctrine. More importantly, they demand different styles of command and control.

Technological advancements offer new possibilities, and at the same time pose new challenges. Fighting forces now have enhanced mobility, reach and firepower, improved sensing, information processing capability and communication range. These advancements expand the area of influence of fighting forces, increase their span of control and blur boundaries. A wider array of weapon capabilities results in further specialisation, complex force structures and task force composition. These make coordination and control of modern day armies more difficult.

Driven by these changes and the need to control increasingly large armies and complex operations, task-decomposition, hierarchy and layering and decentralisation of authority are featured in almost all large conventional armies. With the increasing cost of military hardware, coupled with improved networking and information flow, optimisation and sharing of assets have also become key features in modern day C2 planning. High-value capabilities are held centrally, with information, assigned or applied in areas of the battlefield where maximum returns are anticipated. Environment, technology and control structure are co-evolving into a complex system.

Command strategies have been propounded for centuries even before Sun Tze. It is the domain that relates to the intent, strategies, schema and the ethos of conflict. To assist commanders realise their visualisation of operations, various forms of control systems have been implemented throughout history. These allow commanders to exercise their influence, direct or influence the battles. From the 18th century style of compact fighting force under the control of a single commander-in-chief to the general staff structure of the Prussian Army, command structures evolved along with the nature of warfare and technology. Today, the general staff structure remains the predominant control structure, augmented by ever improving sensing, communication and information processing infrastructure.

Up till WWI, "*command*" encompassed delegation of authority and externalisation of functions. Shortly after WWI, the term "*control*" came into widespread usage. It is probable that during the industrial era, with control theory, which was gaining popularity and the rapid expansion of armies propelled by industrialisation motivated the transposition of control theory philosophy into military operations. "Control" is hence seen as an extension of "command", and "command and control" became inseparable and enshrined in military publications.

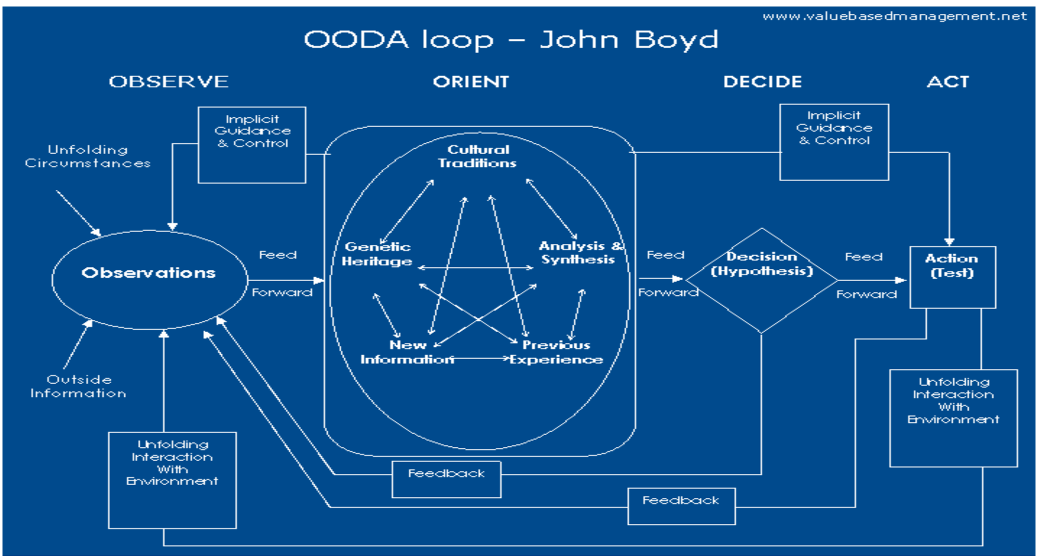


Lawson's Control Theory Model

Influenced by control of engineering systems, present day military operation control is viewed as a system with interacting control loops. It is designed with the underlying belief that it is possible to develop a relationship between observation and its impact on the future, and that it is possible to devise suitable responses and feedback loops to bring the "system" back within "control". This underlying philosophy is clearly visible in Lawson's Control Theory Model.[11]

John Boyd's OODA refined the model and propounded the strategy of shortening own force's OODA loop so as to "get inside" an opponent's decision loop to gain military advantage.

Both models emphasise control, prediction, certainty, efficiency and speed which demand enhanced sensing, massive information collection and processing capability. This quest for greater control and certainty coupled with the promise of information communication technologies (ICT) created a trend of more information being collected, faster processing and dissemination, with the aim of improving control loops and achieving greater certainty. However, certainty of military operations diminishes as the number of interacting elements increases.



Martin van Creveld in "Command in War" points out the danger of such an "engineering approach to war"[12] and stressed the importance of the ability to deal with uncertainty and limited information.[13] Van Creveld further explained how the scientific era influenced and changed the view of war from being an art to that of science, an activity that is decomposable and can be systematically studied and analysed. He argued that the increasing proportion of reservists in armed forces resulted in mechanistic structures being created to train and to recall the reservist in precisely engineered processes, and that long durations of peace and extensive war gaming contributed to the belief that command is simply the regular unfolding of carefully laid plans.

> Returning now to the two basic ways of coping with uncertainty, centralisation and decentralisation, it must be noted that they are not so much opposed to each other as perversely interlocking… Greater certainty at the top (more reserves, superior control) is only bought at the expense of less certainty at the bottom… Properly understood, the two ways of coping with uncertainty do not therefore consist of a diminution as opposed to acceptance, but rather of a different distribution of uncertainty among the various ranks of the hierarchy. Under the first method the security of the parts is supposed to be assured by the certainty of the whole; under the second, it is the other way around.
>
> *Source: Martin van Creveld, Command in War*

In commercial supply management or factory operations, which is relatively stable and predictable, and where risk can be hedged, it is arguably possible to design a near-optimal system such as a just-in-time logistics chain which can anticipate demand based on past consumption rate, pre-emptively trigger re-supplies and engineer the entire transport chain to deliver resources almost precisely when and where needed. Modern-world battlefields however, do not offer such a static benign environment. An example is the Israel-Hezbollah conflict where Israel's concept of a centralised logistics command could not cope with the dynamics of battlefield demands. The central command was overwhelmed which resulted in a near collapse of the supply system. Any perturbations along the chain of supply will propagate and will create cascading downstream turbulence. This is similar to how a vehicle within a steady stream of traffic along a highway, hitting its brakes could can cause instability and traffic jam of several kilometers downstream.

The Law of Requisite Variety[14] states that the number of controls must be equal to or larger than the variety of the perturbations in order to achieve control. By extension of this law, it implies that as the complexity of military operations grows, the variety of controls required will inevitably reach a point of impracticality as the curse of dimensionality[15] sets in. The supply of computational power, theorised by Moore's "law", which only doubles every 18 months, is unable to meet such an exponential increase in demand.[16] Failure to recognise this asymmetry and the continual application of linear control philosophy to an increasing non-linear problem space is neither scalable nor sustainable. To deal with ***complex but non-engineering systems*** such as military operations, an approach other than a mechanistic Newtonian view is required.

NETWORK SCIENCES AND COMPLEXITY

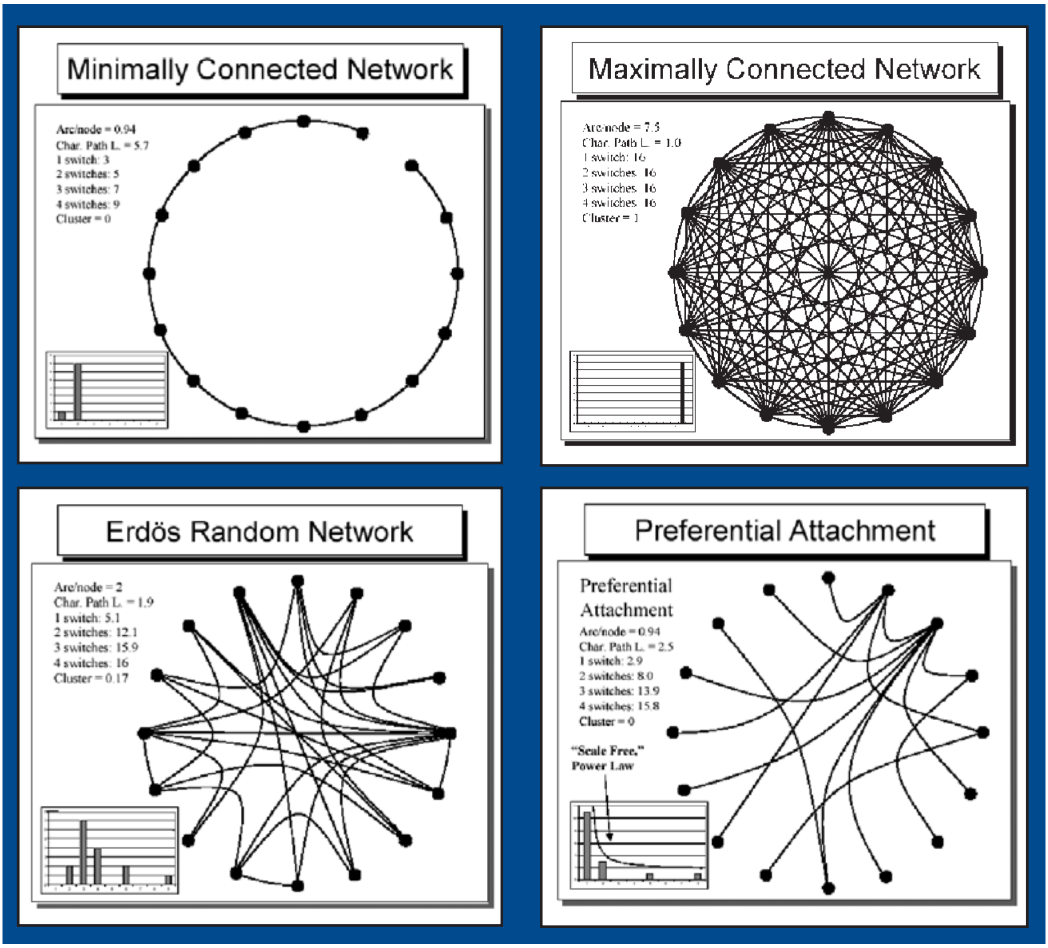
Recent understanding in network science and complexity theory offers a possible alternative control model. Though still in its infancy, network science has been applied to explain real-life phenomena such as the formation and structure of the Internet, World Wide Web page linkages, social networks, evolution and extinction of species, and natural disasters.

Complex system analysis, on the other hand, studies how relationships between parts give rise to the collective behaviours of a system and how a system interacts and form relations with its environment. One of the key interests in complex system studies is the ability of such a system to adapt and change its properties in response to a changing environment – the idea of micro-component interactions and changes leading to macro-system evolution. *The essential idea is that a number of interacting units behaving under a small number of simple rules or algorithms can generate extremely large number of accessible states.*[17]

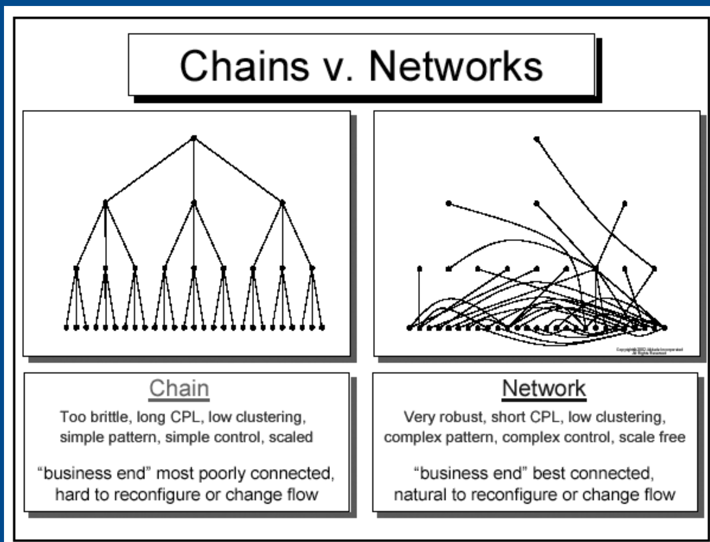
By modelling real-world problems using network models and analysing the micro-interactions between parts based on complexity philosophy, researchers have been able to provide insights on the behaviours of complex systems and exploit these insights to achieve network effects and network-economies.

NETWORKS IN SUPPORT OF MILITARY OPERATIONS

Military control activity is essentially the *control of the quantities, rate of flow and synchronisation of resources throughout the area of operations. Resources include combat units, reconnaissance elements, artillery units, logistics support and bits of information*. Command structures, doctrines and procedure are established to manage these flows. These can be visualised as network models, with resource nodes interconnected via edges required for the flow of information and resources. Network structures range from minimally-connected, to fully-connected and scale-free networks. Different network structures exhibit different properties such as "degrees of separation" between nodes, and average edges per node. These properties directly impact the performance of the network in terms of robustness, effectiveness or efficiency.



Take the global shipping network as an example. While there are several hundreds of ports around the world, the number of calls each port handles follows a power-law distribution, with a handful of ports attracting the bulk of the traffic. Such a network is described as a scale-free network. The average degrees between nodes are significantly reduced because of the existence of a few power-nodes. However, scale-free networks are also at risk of catastrophic failure if one of these nodes fails.[18]



Chain vs Networks. In a chain structure, ***the most important nodes, the ones in contact with the enemy – are the least connected.*** In a network structure, ***nodes in contact with the enemy are well-connected.***

Source: Cares, Sense and Response Logistics, pp10-11

The hierarchical "tree-structure" network is usually the model for control of combat units[19] and allocation of combat support[20] in the military. The average number of edges that resources need to traverse would be the depth of the hierarchy. Crisscrossing edges are created to bring resources from disparate sources and command, to support special missions such as time-critical targeting. Such structures are pre-designed based on postulated scenarios[21] and the assessed type and amount of resources required. Trade-offs between requirements such as responsiveness, resource utilisation and risk of missed opportunities during surge scenarios are made prior to actual operations. The hope is that reality will unfold as close to prediction as possible. However, in an increasingly complex environment, such a hope is increasingly unrealistic and the pre-designed structures are increasingly sub-optimal and more likely to be wrong.

As the number of mission types, possible scenarios and nuances of each type increases, additional controls need to be added. Such an ever-increasing crisscrossing control structure is itself a complex structure that could lead to paralysis. Pre-designed networks with cybernetic-style of control-theory philosophy are unable to deal with the dynamics and complexity of military operations. Adaptive networks, which evolve and adapt to changing environment and demand signals on the other hand, can offer the required flexibility and an optimal response.

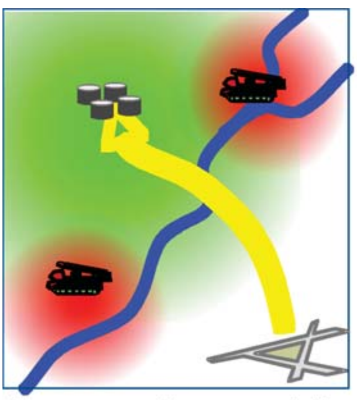
Local Adaptivity, Global Optimisation

By infusing intelligence, which governs local interactions between entities, allowing them to adapt and evolve with each other and the environment, adaptive networks exhibit ever-changing patterns while following some general frameworks. These characteristics give the possibility of creating highly efficient and effective network structures such as scale-free networks, which adapt and conform to the changing needs and dynamics of military operations. The ability to conform to the environment also infuses such networks with self-healing properties, and without clear or fixed power nodes which could result in catastrophic failure of network.

A higher level, network-level intelligence is required to monitor the overall network and issues high-level instructions that change the evolution paths of the network. Such high-level control is required to guard against the network evolving towards a state of criticality[22], to precipitate evolution if it takes too much time to converge towards the desired structure or to change the evolution path of the network due to global level changes in environment for which the original set of local rules no longer applies.

Local Rules, Emergent Behaviours

The challenge of designing such a form of control is the identification of "parameters" and "levers" that will guide the interactions of entities towards the desired emergence of efficient networks (such as scale-free networks) and, at the same time, be able to sense and adapt to changes in environment and demand.



Pheromone Representation
Altarum, 2004, DoD DSC Study

It was recently discovered that the attachment preference between nodes and the fitness-of-nodes (ß) are 2 key factors that govern the interactions between nodes, influence the evolution paths, and eventually shape the property of the network.[23] John H. Holland in *Hidden Order* also identified <u>four basic properties</u> – aggregation, nonlinearity, flows and diversity, and <u>three mechanisms</u> – tags, internal models and building blocks of complex adaptive systems. These findings could be exploited to devise specific rules that govern local behaviours. Each node will make localised decisions based on the rules set, its status, prevailing local environment and status of neighbouring nodes. Through the rules and allowing nodes to respond to local signals, the aim is to derive networks of consistent desired properties and yet adaptive to the changing environment. This tier is characterised by fast dynamics, responsive and adaptivity.

Network Intelligence and Control

Even as desired network properties emerge from adaptive behaviours of entities, it is foreseeable that from time to time, intervention from a network perspective will be needed. Interventions could be carried out to provide focus for rapid concentration of resources to achieve operational objectives. For exceptional cases whereby the local rules fail to achieve the desired effects, a specific intervention may be required to bring entities or the network back onto the desired path. Studies and findings of digital pheromones could be used for such network level control.

To provide command emphasis, "target pheromones" could be placed on objectives or areas of interest. Varying intensity and persistence would then attract the corresponding amount of resources such as sensing, strike and logistics onto the vicinity. Entities attracted to the vicinity will then interact based on local rules towards the attainment of mission objectives. Lines of "boundary pheromones" could be "drawn" to restrict movement of resources between areas. "Perimeter pheromones" could be placed to establish block positions to isolate the battlefield. "Trail pheromones" could be laid to provide guidance for rapid movement of entities through terrain. "Track pheromones" could be placed on a target to activate sensors to track it.

> "The study demonstrated that the pheromone algorithm is capable of handling all the functions identified with only minor changes in its parameters. The surprising versatility arising from such a simple mechanism is one of the more promising aspects of this new CAS of algorithm. Although some tuning was required to get the best performance out of the algorithm, the algorithm was surprisingly robust to large (order of magnitude) changes in its parameters without significant change in performance. This implies that the algorithm should be robust to changes in the scenario and that fine-tuning for each application will not be required."
>
> *Source: DoD, Joint C4ISR DSC, Swarming Concept Development and Utility Study*

Besides digital pheromones, the genetic algorithm governing the interactions between nodes could be modified. However, in a complex situation, such an intervention may yield a nonlinear outcome, not different from the real-world situation of using of monetary policy to intervene and manage economy.

Conventional view of efficient market hypothesis…that everyone in the market will always act in his or her self-interest…In this view, economy is like a bath of water. On microscopic level, individual molecules are doing all sort of crazy things. But in equilibrium, all these microscopic nonsense gets averaged out…Tilt the bath and it is easy to predict how the water will rearrange itself as it seeks equilibrium in accordance with laws of physics. In economics, similarly, pulling a lever to decrease interest rates, for example, should tilt the playing field for every rational person in the market… but no amount of equilibrium thinking can account for such high and rapid fluctuations as the stock market crashes of 1929 and 1987… Dow Jones Industrial Average lost more that 22 percent of its value in one day in 1987…

Source: Mark Buchanan, Ubiquity, pp143-144

CONCLUSION

Technologies, the nature of warfare and the ethos command have co-evolved and changed. However, the control of military operations since WWI still largely relies on a Prussian control structure and control philosophy of the industrial era. Such a static structure and linear control approach is increasingly unable to deal the complex dynamic nature of military operations. On the other hand, understanding in network sciences and nonlinearity of complex adaptive systems could point the way towards a new form of control. A dynamic and adaptive control structure that evolves to match the required complexity of military operations may be possible. The objective is to devise an adaptive system of control that does not draw commanders into the complex world of managing the details; but allows commanders to exercise their intent without being overwhelmed by the increasing numbers of levers, dependences in timetable and rigidities in resources allocation.

There is however, still much research and exploration required to understand and develop the specifics of such a system of control.

As it stands, network theory is not a proxy for a theory of complexity – it only addresses the emergence and structural evolution of the skeleton of a complex system. The overall behaviour of a complex system, which we ultimately need to understand and quantify, is as much rooted in its architecture as it is in the nature of the dynamical processes taking place on these networks.

Source: Barabasi, Taming Complexity

5 DEALING WITH GROWING RELEVANCE AND DEPENDENCE ON COTS/MOTS

COTS – WHAT'S NEW?

Over the past few decades, the development and fielding of advanced technologies for military systems has changed in several significant respects. For one, shrinking defence spending has drastically slowed the pace of developing, perfecting, and incorporating new technologies into existing and developmental military systems. At the same time, small purchases of defence components and poor commercial rates of return and limited potential buyers have deterred manufacturers to enter the defence line of business. The commercial sector, on the other hand, is exploding with innovative, affordable dual-use technologies that could become force multipliers for many military forces. Commercial market pressures and economies of scale also offer militaries round the world the chance to acquire state-of-the-art technologies at a cost lower than what would have been incurred with the traditional development of military-specific systems.

Commercial-off-the-shelf (COTS) is a readily available product that is used "as-is". They are designed to be easily installed and to interoperate with existing system components. MOTS means either modified or modifiable off-the-shelf, referring to a product that is typically a COTS product whose source code can be modified. In the military context, MOTS refers to an off-the-shelf product that is developed or customised by a commercial vendor to specific military requirements. Because a MOTS product is adapted for a specific purpose, it can be purchased and used immediately. For the purpose of simplicity, this paper uses the term COTS to refer to both COTS and MOTS simultaneously.

Usage of COTS in Falklands War

An interesting case study is the example of the Falklands war (1982) between the British and the Argentineans. Military strategists were questioning whether Britain still had the capability to conduct a war 8,000 miles away in another hemisphere. The British Ministry of Defence, strapped for funds and short of time, decided that they would use commercial transport ships as supplemental "aircraft carriers" to launch Harrier vertical take-off fighters against the Argentineans. This makeshift strategy, which demonstrated the robustness, flexibility and cost-effectiveness of commercial solutions to military requirements, helped to open doors for more COTS adoption within the ministry.

Source: http://news.scotsman.com/topics.cfm?tid=291&id=365372002

WHAT THE 3RD GENERATION SAF CAN GET FROM A COTS-BASED APPROACH…

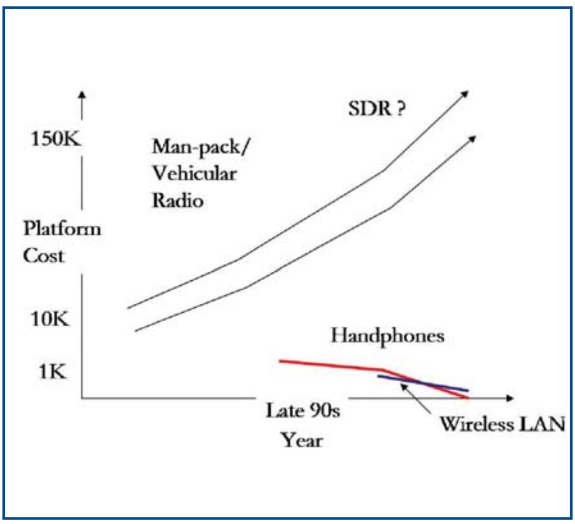
Affordability: Lower Costs

It is in the interest of defence programs to take advantage of existing cost-conscious, market-driven commercial technology. By leveraging on the huge investments already made by private industries in leading edge process technologies, the military can reduce development, procurement, and maintenance costs.

Tapping into Commercial Radio Development

The rapidly mobile forces of the future will continue to require the most advanced access to real and near-real time information from anywhere at anytime. With well-trained, mobile forces and rapidly deployable communication systems, the military can respond robustly and quickly to developments in the battlefield. The communications system constitutes the most fundamental infrastructure through which soldiers can exchange information and data. It is the fundamental building block upon which IKC2 builds other applications.

Current tactical VHF/HF communication radios can only provide voice or very limited low-data rates. This means that commanders are limited to exchanging little information and as a result, their situational awareness is largely degraded. Also, with the rising cost of military radios[24], massive proliferation of ubiquitous communication to the lowest echelon would be beyond the budget means. In addition, their development and advancement has been generally slow, in comparison to their commercial counterparts.



In contrast, the development of commercial communication techniques and solutions has been rapid, fuelled by the civilian needs, which far outweigh that of the military. Commercial Wireless LAN such as WIFI is several orders cheaper yet offer several orders more bandwidth than that of traditional data radios. The following diagram depicts the trend of rising tactical radio platform costs while commercial radio costs are falling.

Tactical Platform Cost vs Commercial Radio Pricing

Secured Wireless Local Area Network (SWLAN) is the US Army program that exemplifies the usage of commercial wireless networking technology – the IEEE 802.11 (WiFi) standard waveform is modified with highly directional antennas to provide Low Probability of Intercept (LPI) and Low Probability of Detection (LPD) capabilities. SWLAN is also equipped with Type I encryption to provide a highly secure, easily deployable wireless network for their Future Combat System (FCS). (See insert for more details)

Other emerging standards, such as World Interoperability for Microwave Access (WiMAX) are promising COTS-based wireless wide-area communication protocols that can be tapped by the military to improve data throughput in the field. WiMAX offers approximately six times more throughputs (actual bandwidth) than WiFi, and it is coupled with more advanced features such as Quality-of-Service (QoS).

The SAF has experimented with some prototype commercial WiMAX solutions as a way to provide high-bandwidth, low latency communication means between *distributed* command posts. This has provided the future Command Post (CP) with richer and faster data, even though they are separated by great distances. This concept is critical as it significantly reduces the signature of a single command post and thus enhances military survivability. Doctrinally, WiMax has allowed warfighters the opportunity to concentrate on new concepts of fighting and information sharing.

Secure Wireless LAN for US Army

The first Secure Wireless Local Area Network (SWLAN) radio ever deployed during wartime has made combat communications in an urban environment easier and more secure. The radio was developed and fielded by a team led by Northrop Grumman Corporation for the U.S. Army. Newly upgraded SWLAN radios are installed in Stryker Brigade Combat Team Three (SBCT-3) vehicles, have been used during operations in Iraq since August 2005 – the first combat deployment for this type of technology in U.S. history.

SWLAN radios are designed to be more mobile and easier to use than conventional secure communications systems, which rely on extensive cabling, making set-up time-intensive and cumbersome. SWLAN radios combine commercial-off-the-shelf equipment with National Security Agency-approved encryption capabilities and are intended to establish local area networks among Tactical Operations Center (TOC) vehicles used for battlefield command and control. SWLAN provides encrypted Ethernet communications at five megabytes per second over a one-kilometer radius and supports simultaneous operations at the 2.4 and 4.4 gigahertz bands, with multiple non-overlapping channels. Built for affordability and reliability in a tough combat environment, the SWLAN commercial-off-the-shelf architecture supports future user needs and system upgrades.

Source: http://www.defenseworld.net/C4ISR/news.asp/var/11089-DefenseAerospacePressnews-1

Other important COTS radio technology developments include Software-Defined Radio (SDR) which promises to do for the wireless industry what the PC and object-oriented software and operating systems did for the computer industry: drive down costs and proliferate wireless applications into every aspect of daily life. Current available SDR radios are still expensive and limited in their capabilities due primarily to their developmental infancy. However, as the momentum of the industry gathers pace and with more advanced technological breakthroughs in the coming years, SDR will be a force to be reckoned with.

Infusion of Advance Technologies into the Military Context

The push to use COTS is driven as much by economics as it is by technological advances. The explosive development of technologies such as computing, storage, electronics miniaturisation has been fuelled by strong commercial needs. In turn these dual-use key technologies are instrumental to infusing higher technologies into military systems.

COTS Turned Dumb Bombs to Smart Bombs

In the 1990s, following the Gulf Conflict, the U.S. recognised that laser designation does have serious limitations and initiated several projects to examine solutions. One of these was Joint Direct Attack Munition (JDAM) which consists of an add-on kit for existing iron bombs. The kit comprises a tail unit containing the GPS (Global Positioning System) and 3-axis INS (Inertial Navigation System) guidance system. Four fins are attached to this to provide both flight control and lift, and stabilisation (and additional lift) is provided by strakes attached to the sides of the bomb. By utilising GPS/INS the weapon becomes fully autonomous once released while being unaffected by weather or target conditions. Using standard commercial off the shelf (COTS) components can also hold down the cost of the system. Each JDAM kit is estimated at US$14,000-20,000 which is cheap for a high tech upgrade of "dumb bombs".

During some 245 live trials at White Sands Missile Range in New Mexico, JDAM achieved a flight reliability rating of some 95% and CEPs (Circular Error Probable) of some 9.6 metres (in GPS guided mode, INS only mode would result in CEPs of around 30 metres). These trials have also proved and weapon's all-weather ability, which in itself is a significant improvement over laser-guided ordnance.

Source: http://www.eurofighter-typhoon.co.uk/common/AG/iron.html

Powering Electronics and Advanced Material for Next-Generation Military Platforms

From electric-drive ships to hybrid land rovers, military vehicles that rely on electric motors rather than the typical internal-combustion engines can soon rely on *advanced power electronics* to handle huge voltages in their drive trains. Being more fuel efficient, hybrid and electric vehicles represent one way to cut costs especially when oil prices are rising. Another advantage is the lower noise level that the electric engine produces.

Power components also handle *extra-low voltages* so that an unattended sensor can extend its operational lifetime from days to perhaps months.[25] At the soldier level, scientists are also trying to shed the huge load of batteries soldiers need to carry as a result of the increasing array of electronic gear that troops have to carry into the networked battlefield.

Many system designers are seeking electronic component *miniaturisation* to further reduce the size and weight components in Unmanned Aerial Vehicles (UAVs) or Unmanned Ground Vehicles (UGVs). In turn, the extra payload can help unmanned vehicles to stay longer in the battlefield, thus providing more persistent service to the soldiers. Lighter and durable materials, such as carbon fibre, Kevlar and Nomex honeycomb, are increasingly being used by UAV manufacturers and even commercial aircraft.

Shorter Development Time for Military System

The developmental cycle of products by government or military agencies specific to military environment is often long (measured in decades versus tens of months for commercial development) and troubled with project issues (uncertain user requirements, budget issues etc). Hence another reason for the adoption of COTS is often to dramatically reduce the development-acquisition cycle time, hence achieving a faster turnover duration in delivering complex military systems. Moreover, COTS technology can potentially be used as "gap-filler", while more time is made available to specific military components that do not meet initial specifications, thus allowing for system to be commissioned at an earlier date.

Game Technology for Rapid Military Testing & Experimentation

No entertainment industry has posted the same pace of growth generated over the last decade by the video industry. With the further technological enhancement in *graphics processing* and *cheaper memory cost*, the gaming industry is showing no signs of slowing down and it is set to surge further for the next few years. Retail sales in US alone recorded more than US$10 billion in 2005.

Most of these games are highly accessible to all and strongly related to military activities such as first person shooter games, flight Sims, naval Sims, war-games, role play games, city Sims & people Sims. Moreover, the software development kits for these games are easily available and often free. At a few tens of dollars per copy and affordable licensing fees, the military can easily exploit them to *recruit* and *train*. Such video games are easily *modifiable,* such as the underlying skins, maps and rules of engagement. They can be used for rapid prototyping and as proof-of-concept tools.

Technology Refresh

- Graphics processing power "leap" every 6 months
- Evolution of game technology
  - "Play Station" - 1994
  - "Play Station 2" - 2000
  - "Play Station Portable", Xbox360, Wii - 2005
  - "PS3" - 2006
- Physics Chip
- Projected 10Ghz Chip by 2011

As this trend continues, video games are a powerful means of gaining military advantage. The younger generation of Singaporeans is increasingly hooked on computer and video games. Their familiarity with video games is an added advantage for faster military adoption of COTS games for doctrine development and training. As players practice behaviours in a virtual context, the games change their reflexive responses and hone their fighting skills.

DSTA and SAF have a long history of exploiting COTS for military simulation. Thus far, their experiences have shown positive results, spurring future projects and wider acceptance.

Exploiting Web Services for Information, Command & Control (C2) System Development

Extensible Mark-up Language (XML) makes it possible for systems in remote locations to exchange and interpret documents without human intervention. This ability to automatically send, retrieve, interpret, transform, and process the data in electronic messages is critical to the conduct of electronic business. Its relevance to the military context is salient in situations when time is of the essence.

The use of COTS XML and web services technologies for current and future command and control (C2) systems has shown great promise as a rapid channel to *minimise proprietary interfaces* and *data formats*. It facilitates cross-Service interoperability and network-centric application integration.

The use of COTS components as core elements of military information systems is now widespread, due mainly to the impact of the Internet since the early 90s as well as the consolidation of programming languages. XML is one of those ubiquitous new technologies that fuelled further commercial web applications development. According to a lead investigator working in MITRE, a US non-profit public research company, XML has been adopted[26] in military applications ranging from intelligent, surveillance systems to medical, and network planning tools. The military is also moving towards a common look and feel between IT in the home, barracks and battlefield.

STRATEGIES FOR COTS EXPLOITATIONS

The adoption of commercial products and components is not necessarily straightforward nor risk free. COTS strategy is not the "silver bullet" that answers all military needs. There are disadvantages and issues related to the usage of COTS. We need to recognise them, and selectively exploit and adapt COTS within a military context, in ways that best serve the needs of the SAF.

Smoothen the processes of COTS integration.

Process and product changes require a new way of doing business when COTS components are involved. New processes must be inserted as the manner in which systems are acquired and sustained moves from a build- to a buy-orientation. Both military personnel and contractor personnel must therefore be educated and trained to accommodate this changeover.

Soldiers have to be re-trained to use the new COTS software or hardware. Using the available resources from the commercial sector, we can tap them to educate and to re-train our staff. However, they can be easy prey to external poaching as their skills would be equally valuable outside. Hence, a robust staff retention strategy will be needed as well.

Balanced Approach: Adopt, Adapt & Develop

The core business of commercial-based entities will always remain the commercial user. Consequently these COTS technologies may not fulfil all the needs of the military. Governments will need to make further investments to upgrade these COTS to military specifications that take into account the operational context and a harsh environment. It is clear that the blanket adoption of COTS is not desirable. Rather, we should pursue a balanced approach of adopting, adapting, and developing COTS technologies. The SAF should pursue the policy of adopting COTS whenever possible. In so doing, we will benefit from COTS standards without being tied to one specific vendor or product, and hence maintain a certain level of independence and greater technology currency.

When an adoption strategy does not work well, adapting in a military environment is the next solution to consider. Adapting will include some level of adoption at either the component or sub-system level. In building complex systems, which the SAF does often, interoperability of the sub-systems dictates that some level of adaptation is needed. Adapting will allow for quicker and inexpensive system integration.

Development is necessary for those unique circumstances where no commercial solution can form a partial or total answer. To mitigate risk, military development should be pursued as a partnership where industry can be "seeded" with an initial investment (of money or technical knowledge). In turn, if the seed is properly nurtured, it can grow to become a strong manufacturing base upon which other new beneficiary technologies can grow.

Commercially-Oriented

Promoting the use of COTS is not without its fair share of detractors. A general lack of understanding of COTS products themselves is not uncommon. Commercial products suffer the reputation of not being "robust" enough for military usage. The truth is the gap between industry grade products and military-grade ones is fast diminishing.

It would be useful for MINDEF to consider *exchange programs* with the industry whereby civil servants are "loaned" to industry on a temporary basis. Industry people can also be seconded to the Ministry for a short time in order to promote a clear understanding of how each is organised, how corporate decisions are taken, and the nature of the problems they both face in an increasingly competitive world.

MINDEF staff needs to gain first-hand experience in a commercial environment. The result of such a process is a much closer relationship between industry and the Ministry – one that better promotes a free flow of ideas across government and industry boundaries.

CONCLUSIONS

COTS technology is not a panacea. However, the use of COTS offers the best hope for the 3rd Generation SAF to modernise its future military capabilities with leading edge technologies in an era of declining defence budgets and limited leverage over suppliers of militarily relevant technologies. The biggest benefit of using COTS items is the ability to put more capability into the hands of the warfighters faster. This is particularly important as mission requirements become less predictable and as traditional acquisition cycles become more prolonged.

Section Two

Building Upon a Strong Foundation

6 OPERATIONALISING IKC2 FOR THE 1ST SPIRAL, 3RD GENERATION SAF

INTRODUCTION

26 Dec 2004. The world awoke to a level of devastation never witnessed before. Tsunami waves, caused by an earthquake off the island of Sumatra, had pounded the shores of several countries in South and South East Asia bordering the Indian Ocean. In an instant, the disaster left a quarter of a million people dead or missing; and millions more homeless and in need of immediate emergency relief. The SAF Joint Task Force (JTF) was activated to provide disaster relief. Code-named Operation Flying Eagle (OFE), the relief operations, the largest ever undertaken by the SAF with about 1,500 personnel, saw Naval ships, helicopters, transport planes, ground forces and other civil agencies working together.

OFE made two things apparent in the SAF. Firstly, the success of the operation was made possible because of the integrated efforts of the Army, Air Force and Navy. Helicopters from the Air Force and Landing Ship Tanks (LST) from the Navy were employed to reach isolated areas within the affected areas. Likewise, land troops required the Air Force to insert them into areas not accessible by roads, while they in turn cleared landing sites for both their Navy and Air Force counterparts. In working off each Service's strength, the SAF was able to be one of the first foreign HADR forces deployed into Aceh. It was a testament to the capabilities of the JTF and its integrated capabilities.

Secondly, OFE highlighted the importance for the SAF to have a Joint Task Force capability that is able to operate in a cross domain environment of air, sea and land, while also integrating the multiple functional capabilities of logistics, intelligence and civil-military operations. This is characteristic of the 3rd Generation SAF's ability to deal with the complex and challenging security environment.

> *"The SAF was able to respond swiftly and carry out this mission effectively because it had over the years developed a flexible set of capabilities and trained its people to respond to unexpected circumstances."*
>
> **Mr Teo Chee Hean**
> **Minister for Defence**

ONE SAF

The capability of the Joint Task Force in OFE is but one facet of the SAF's journey to becoming a 3rd Generation force. The 3rd Generation SAF will be one that is integrated, networked, cohesive, synergistic and self-synchronous. In truth, this vision had been mooted as early as 1970 by then-Defence Minister, Dr Goh Keng Swee. Dr Goh believed in the advantages of common systems and infrastructure, and had wanted the doctrines and systems of the Services to be harmonised to achieve this. However, this did not come to fruition, as the focus at that time was to build up conventional capabilities quickly, with emphasis on building within-the-Service competencies and capabilities.

The SAF today is uniquely poised to move towards being an integrated force, becoming *ONE* SAF. The critical conditions that had changed since 1970 to allow this are in two areas.

Firstly, each of the Service pillars has matured and is developed enough within its own domain competencies to be able to undertake areas of integration and interoperability. The Joint Staff has also developed significantly as an instrumental interface between the Services. This has allowed the Services and the Joint Staff to re-organise their key structures in order to better meet integration and interoperability needs. Secondly, the advances in communication and networking technology have increased the possibility, level and extent of cross-domain integration between assets. This has allowed the wiring up of platforms and capabilities across domains and between the levels of operations.

> *"ONE SAF is more than thinking joint, it is thinking SAF. To operationalise this will require a system based on strong networks that are clearly established across all related and relevant entities in the Joint Staff and Services – to optimise and build on each individual node of excellence or center of knowledge wherever that might be as part of a larger matrixed organisation."*
>
> LG Desmond Kuek
> Chief of Defence Force

THE JOURNEY THUS FAR

The SAF has already embarked on its transformation journey towards a 3rd Generation SAF prior to OFE. The conceptualisation of IKC2, an important ingredient of an integrated and networked force, started as early as 2002 with experiments in network-centric concepts and capabilities. Slices of these concepts and capabilities were fielded in exercises such as Ex. Forging Sabre and Ex. Wallaby, offering glimpses of the shape and form of the 3rd Generation SAF.

Exercise Forging Sabre 2005

Conducted in the Mojave Desert in the US in 2005, the focus of the exercise was to demonstrate the operational benefits of IKC2 to achieve closely networked and highly responsive sensor-shooter linkages across various air and ground-based SAF platforms. Operating with the information from UAV, the Special Forces were able to leverage on the linkages established to call upon a range of fires from Artillery guns, F-16 fighters and Attack helicopters (AH-64D) to achieve its mission.

Exercise Forging Sabre

AH-64Ds and Artillery work in synergy to take out enemy forces

Schematic of Air-Land Integration

Ground troops, inclusive of Commandos, operate in tandem with air platforms

"It gives us great confidence when you have complex technology that you can integrate together, and it gives the SAF great confidence in knowing that it works, and we are reaching a high standard. When we embarked on this journey of the 3rd Generation SAF, one of the fundamental aspects was to use superior platforms, superior technology to multiply our effects."

Dr Ng Eng Hen
Minister for Manpower
and 2nd Minister for Defence

<u>Exercise Wallaby 2006</u>

Ex. Wallaby, over the past few years, had been experimenting with new concepts and capabilities in the area of air-land integration, using IKC2 systems. In the 2006 Ex. Wallaby, these capabilities were put together to share information from command posts down to the soldier's level. For commanders, information from sensors and fighting troops were fused in a digitised command post for superior battlespace awareness to support decision-making. The connectivity achieved also provided effective command and control of the forces deployed on the ground. At the tactical level, the Battlefield Management System (BMS) enabled shared awareness amongst the fighting troops to synchronise their fires and manoeuvre. In addition, the ground forces were also networked with the air assets to share timely information for the smooth conduct of integrated operations.

<u>Exercise Wallaby 06</u>

Air assets such as AH-64Ds, participating as part of the Army exercise

Digitised Command Post, providing C2 of deployed assets

Ground assets such as SPIKE missile launcher, provide firepower on the ground

BUILDING THE 3RD GENERATION SAF

"The 3rd Generation SAF is a calibrated and flexible force, able to conduct a spectrum of operations from peace to war."

MG Neo Kian Hong
Chief of Army

Having demonstrated the benefits and possibilities of IKC2 over the past years, the SAF is now ready to embark on the 1st development spiral of the 3rd Generation SAF. This 1st spiral will build on the current operational baseline of the SAF High Readiness Core (HRC), where 24/7 operational readiness had been established against the wide spectrum of peacetime and troubled peace contingencies.

In the near to medium term, three thrusts have been identified to drive the SAF towards the 3rd Generation. These include **Operationalising the 1st spiral of the 3rd Generation SAF, Nurturing First Class People in a World Class Organisation, and Engaging our People towards Stronger Commitment and Greater Excellence.**

The **first thrust** covers Capability Development, Operational Development and Organisational Restructuring to achieve an integrated force. This involves progressing from experimentation to achieving real operational capabilities.

Eventually, capability and operational developments will allow the SAF to be able to operate with three characteristics.

- The first is **Integrated Operations.** The SAF will be able to fight with an integrated employment of air, sea and land assets to enable capability overmatch in fulfilling mission requirements. For example, traditional land battles will now be fought with support from both air and sea assets to enable greater mobility, fires, intelligence, survivability and sustainability.

- The second is **Precision Fires and Manoeuvre.** The ability to bring fires to a target very quickly and accurately so as to allow the SAF to target the enemy's critical and most vulnerable nodes. Manoeuvre forces can then be employed to fight key battles at the appropriate time.

- The third is **Information Superiority**. This is the ability to attain timely, accurate information and be able to use it to enable situational awareness across domains. There will be an increased usage of unmanned technologies, such as the UAV to achieve this. Information superiority will enable forces to manoeuvre and apply fires in a more precise manner.

In tandem with capability and operational development, the SAF needs to re-organise itself structurally to support the vision of the 3rd Generation SAF. This will require the SAF to be more flexible and interoperable across the Services in the areas of capability development, operational development and training.

The **second thrust** focuses on nurturing people within the SAF. It will seek to prepare them not just for the present, but more importantly for the future. This will involve training in the affective domain to enable three outcomes; to possess an innovative and collaborative mindset; to think and act integrated; and to engage in continual learning.

The **third thrust** involves the engagement of the hearts and minds of the people within the SAF.

OPERATIONALISING THE 1ST SPIRAL

> *"The 3rd Generation force will continue to meld technology, operational knowledge, innovative concepts and deep training competencies into a sustainable and sharp capability edge."*
>
> RADM Chew Men Leong
> Chief of Navy

The remainder of the article will focus on the first thrust, discussing the capability development and operational development that will take shape within the 1st spiral. It will look into the capabilities that can be afforded by having the attributes of *ONE* SAF within the various missions. Moving further, it will discuss how IKC2 has been used to provide cross-domain connectivities that enable the SAF to achieve its mission imperatives. The aim is for the 3rd Generation SAF to operate based on:

- Integrated Sensors and Shooters, where the SAF is able to have timely and accurate intelligence so that the appropriate shooters can be assigned to achieve the desired outcomes.

- Interdependent Fighting Systems, where each Service will fight interdependently as part of the larger SAF effort. For example, efforts in one domain will impact on the progress in another domain, illustrating the interdependence of decision-making and asset allocation.

The following sections will cover the Command and Control (C2) doctrines that are in place to enable a networked and integrated SAF. Using the C2 doctrines as the framework, the capability development and operational developments will be discussed.

Integrated, Cross-Service, Task-Organised Forces

Traditionally, the SAF has been operating via the Services, which prosecuted individual domain campaigns. Any Joint operation will involve the coordination of assets for employment across domains. An example is the allocation of fighters to support ground operations. However, as the SAF moves towards a more networked and integrated force, a model of the Joint Task Forces will be employed. Although there will still be Air, Land and Maritime operations, the difference is that these operations will no longer be prosecuted via single Service capabilities alone, but with an integrated Task Force. In each operation, the Task Force will be configured to best meet the mission demands in the air, land and maritime domains. The Task Forces can be formed using assets from any Service. A unified SAF Campaign HQ will be in place to command and control all the Task Forces employed.

Operationalising the SAF High Readiness Core (HRC)

The SAF HRC will be operationalised to provide 24/7 capability against the wide spectrum of contingencies during peace and troubled peace. These high readiness forces will be task-configured for mission-effectiveness, while leveraging on the specialised competencies from the respective Services and functional groups. For instance, Island Defence HQ will have elements from the Army Protection of Installation (POI) units, Air Force's Integrated Air Defence units, Navy's COSCOM, as well as components at the national level, from the homeland agencies such as the Singapore Police Force, Police Coast Guard and Civil Defence.

Conventional Warfare

> *"When the SAF fights, it is not as a single Service. We fight 'integrated', using the strengths of the Army, RSN and RSAF, achieving true synergy."*
>
> BG(NS) Bernard Tan
> Former Director, Military Intelligence

While the SAF operationalises its HRC to deal with a wider spectrum of peacetime contingencies, its core mission has not changed. The SAF is still designed for a high tempo, conventional war situation. However, it will now operate in a different way, with greater integration and precision. The SAF has been steadily investing in cutting-edge capabilities that enable it to fight with speed and precision. These will be instrumental in enabling the SAF to prosecute various mission imperatives, as well as in enhancing the shape and texture of the SAF as a whole.

- In the area of integrated sensors and shooters, forces will be able to leverage on a network of manned and unmanned sensors. This would provide timely and accurate situational awareness to the various units, enabling them to execute the assigned missions. Targets can be acquired and engaged via multiple means, attacked at multiple points simultaneously, and in different ways. The sensor-to-shooter cycle is reduced to a matter of minutes and seconds from the time that a target appears, to it being positively identified and engaged.

- In the area of interdependent fighting systems, units will fight as part of a larger SAF effort. Island Air Defence efforts undertaken by the Air Force will be augmented by Naval platforms. For example, the frigates' advanced radar can help to enhance the surveillance coverage to better achieve our air defence mission. Air assets, in turn, can "Dominate From the Air" to shape the land campaign, allowing ground forces to move in and capture the objectives.

IKC2 IN THE *ONE* SAF

> *"We are fortunate that information technology has opened up new possibilities for us. Network technologies and concepts allow us to disperse our forces so that they are less vulnerable, while at the same time being able to bring together a concentration of power – 'virtual mass' – to hit the enemy."*
>
> Mr Teo Chee Hean
> Minister for Defence

IKC2 is an important thread running through the SAF efforts to achieve integration and interdependency. Services have made significant strides in IKC2 development for within-the-Service connectivities and some levels of cross-domain connectivities. These include:

- **Battlefield Management Systems (BMS)** have allowed commanders to have better communications between the troops. Information on the locations of friendly and enemy forces can be disseminated quickly and efficiently. Commanders at the headquarters can send out messages to deploy forces using functions similar to the SMS function on the mobile phone. Via an electronic map, soldiers can use the BMS to indicate newfound locations of enemy forces. The BMS also creates a common picture of the battlefield for troops operating different platforms; for instance, between the fighting forces and the artillery guns, enabling them to see and fight better as a system-of-systems force.

- **Combat Management Systems (CMS)** on the frigates have state-of-the-art data fusion, sensemaking and decision-support engines, which increases the frigate's battlespace awareness and orchestrates its sensors and weapons employment. Sensor-shooter loops will be short, giving the enemy little time to react. This allows the frigates to offer many battlefield options and increases the range of operational effects that the SAF can bring to bear on the adversary.

These significant strides mean that the stage is now set to move to the next level of achieving greater cross-domain connectivities. To do this, the *SAF One Network* will be established. The *One Network* is not about connecting every platform and last soldier; rather, it will be done to meet specific mission imperatives. Ultimately, the *One Network* will enable a systems approach to warfighting and giving power to the edge, so that the tactical forces and strategic Corporal can call upon the most suitable cross-domain capability in the SAF to achieve the desired effects.

System Architecting and Integration

> *"As we implement the One Network, we should also consider leveraging the capability and talent in our defence industry."*
>
> Prof Lui Pao Chuen
> Chief Defence Scientist

The integration of operational concepts with system development has been key to the SAF's development of the *One Network*. On one hand, substantive competencies have been built up in the SAF C4 Community, DSTA, DSO and other local industries. The Operations community, on the other hand, has been actively defining the operational concepts, doctrines, information flow and process loops. This has given the technical agencies the clarity and direction to provide appropriate system solutions to meet the demands of the 3rd Generation SAF. More than this, the Operations community is constantly levelling up their own knowledge in networking and communication technologies. This allows them to not only better appreciate the pace and progress of technological advancements, but also facilitates greater understanding between the Operations and Technology communities. Such strong Ops-Tech integration has enabled the SAF to develop capabilities at a much quicker pace.

Within the 1st spiral, some of the IKC2 developments that will take shape to enable cross-domain connectivities include:

- **Digitised Command Posts.** Command Posts will have IKC2 systems that enable them to operate in a multi-domain environment. It will be able to leverage on sensor information from different domains to better execute missions. For example, a Division Command Post on the ground will be able to receive information from UAVs and transmit this to its tactical forces.

- **Digital Communications**. This will allow exchange of information between platforms in different domains to achieve shared situational awareness. Such systems will allow the 3rd Generation SAF to have an interdependent and cooperative fighting system.

- **Command and Control Information Systems (CCIS)** will be developed, using an enterprise approach, to become interoperable so as to allow greater integration across the Services. A central software library of re-usable software modules will be systematically consolidated to achieve efficiency in development time and cost.

- **Modelling and Simulation (M&S) Systems** have enabled effective training, operational mission planning and rehearsals, decision support, and military experimentation for the SAF. Moving forward, systems such as the land-based Battlefield Instrumentation (BFI) system, Air Combat Manoeuvring Instrumentation (ACMI) system and Fleet Instrumented Training System (FISTS) will be integrated to facilitate realistic cross-domain training for integrated operations.

ORGANISATIONAL RESTRUCTURING

> *"Holding on to our existing structures would constrain our improvements to doing the same things better, but without a quantum leap in our overall capability. We should transform our structures to reap the full synergistic potential of technology and concepts."*
>
> MG Ng Chee Khern
> Chief of Air Force

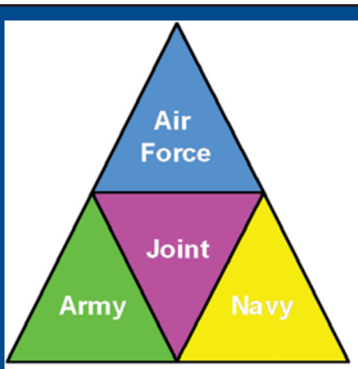
Having discussed the capability and systems development of the *ONE* SAF, this section will now focus on the need for organisational restructuring. To become more networked and integrated, there is a need for the SAF to develop organisations that can better integrate and inter-operate with each other. These structures should be matrixed across functional lines to allow a stronger, more integrated and networked orientation. Such an organisational model will complement the changing nature of work that is increasingly characterised by greater complexity, cross-competency and technological sophistication. Three areas will be discussed to demonstrate the SAF's movement in this direction.

To guide the SAF in organising itself in peace and war, three organisational principles will be used:

- **Integrated Task Forces.** To create integrated fighting systems, Task Forces must continually train and operate in an integrated manner so as to enable greater synergy.

- **Interdependency.** The expertise and experiences derived in each domain will be leveraged to enable the SAF as a whole to build capabilities and functions for key missions.

- **Functional Integration.** Functional areas within the SAF, such as Intelligence, Logistics and Manpower will be functionally integrated rather than be managed in silos. This will allow a synergistic development of functions and allow optimum management of resources such as human resources.



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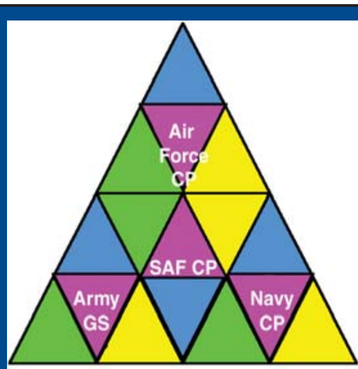

Future

Integrated and Matrix Organisation

The concept is to break away from a Service-centric model of the past to an organisation that is integrated across type and function. This will allow greater synergy in Capability Development, Operational Development, Training and Resource Management.

Building Hubs and Communities

The Joint Staff will establish a Capability Development Hub, an initiative to hub the Plans Community to create a holistic and integrated approach to driving strategic planning and capability development for the 3rd Generation SAF. This will ensure that developments in all areas are synchronised from the start to the end of the developmental process.

In operations, all the SAF Ops Centres are networked to form a community of Ops Centres. This community will perform ops control functions and reach back to Joint and Services in support of current operations. It will also provide the SAF HQ a full range of resources for planning and execution, leveraging on both Joint's and Services' domain expertise in areas such as Intelligence, Logistics, Human Resource (HR) and C4.

The 3rd Generation Army is a full spectrum force that needs to maintain high operational readiness while it develops and sustains its full force potential. To achieve this, the Army has re-organised itself into the HRC of operationally-ready units to deal with peacetime contingencies on a 24/7 basis, while creating the capacity for the rest of the Army to raise, train and sustain its forces. The HRC is scalable, with the flexibility to tap on units and resources from the rest of the Army when needed. This system allows the Army to manage our resources more effectively and efficiently.

The 3rd Generation Army's corporate headquarters – the General Staff, also needs to be more network-enabled to handle complex, cross-functional and inter-Service operations. To this end, the General Staff has reorganised itself into five overlapping hubs of practice and knowledge; leveraging on the natural synergy around the three core businesses of Operations, Training and Capability Development, as well as the supporting resource functions of Combat Service Support (CSS) and HR. This structure allows the Army to be organised for effectiveness and efficiency. These five hubs are the Operations Hub, the Development Hub, the Training Hub, the HR Hub and the CSS hubs, networked together to achieve new heights in organisational excellence.

Task-Oriented Organisations

The Republic of Singapore Air Force (RSAF) has also undertaken new, more flexible and capable structures to better handle the full spectrum of operations from peace to war. The new RSAF structure will see the amalgamation of six formations into that of five Commands: the Air Defence and Operations Command, the Air Combat Command, the Participation Command, the Air Power Generation Command, and the UAV Command. These five new Commands will enable a greater level of integration with the Army, Navy and Joint Staff. The restructuring shifts the focus from a geographical and hardware-based organisation to a more mission oriented one, and will allow the Commands to quickly and efficiently tap the resources of six formations.

Five Commands of RSAF

- Air Defence and Operations Command (ADOC) is the first of the five Commands to be stood up and will allow the RSAF to maintain its operational readiness against security threats, and at the same time, allow the RSAF to continue its overall transformation journey.

- Unmanned Aerial Vehicle Command (UC) is established to harness the full potential of unmanned systems. The conduct of sustained surveillance systems is key to the fighting concepts of the 3rd Generation SAF. As unmanned capabilities are essential in all operational domains, the UC will be made up of personnel from all three Services.

- Participation Command (PC) will drive the integrated development and deployment of air power for the land and maritime theatres, and strengthen the level of integration of air support with surface campaigns.

- Air Combat Command (ACC) will lead the development and operationalisation of the SAF's integrated air combat capabilities, bringing together all the RSAF's fighters and transport aircraft, for greater operational synergy and professional development.

- Air Power Generation Command (APGC) will unify and strengthen all airfield operations of the RSAF, to provide robust and continuous launch and recovery operations for all air assets.

Functional Integration

Capability-wise, the Republic of Singapore Navy (RSN) has sought to sharpen her warfare capability development with the creation of the Warfare Centres by integrating resources from both the Plans and Logistics communities. This has enabled the RSN to achieve a knowledge-centric warfare approach to enhance the warfighting effectiveness of our platforms and combat systems. Moving ahead, the RSN will evolve to be a networked force that is both able to leverage on and support other SAF forces to achieve the system level response for the assigned SAF mission. The Formidable-class frigates with her capabilities can act as a critical node, drawing and providing inputs from both naval and RSAF assets to assist in National Air Defence or support the RSAF in the prosecution of air threats.

Organisation-wise, the RSN is reviewing its organisation and structure to ensure that it is able to respond swiftly and effectively to maritime security threats on a sustained basis. The Navy seeks to leverage on the SAF and partners from the national agencies and maritime community to adopt a "whole of government" approach towards maritime security. At the functional support level, the RSN is exploring concepts to centralise the front-end support with the creation of Logistics and Personnel/Administrative Hubs to directly support the ships at the naval bases.

INVESTING IN THE HUMAN CAPITAL

No amount of technology or cutting-edge capabilities will provide the answers to wars or winning wars. The key difference will lie in the people, and how well they are nurtured, trained, managed and engaged to harness and leverage on all the new technology coming aboard. They will also be critical in assimilating technological advancements with new warfighting concepts.

Therefore IKC2 training is an important facet in the journey towards the 3rd Generation SAF. This can be seen at two levels; firstly, IKC2 training enables the levelling up of technical knowledge that is critical for quick capability development; secondly, IKC2 training, due to its nature, fosters greater understanding and ease in operating within an integrated environment.

These issues, among others, will be addressed as part of the second and third thrusts for the *ONE* SAF, addressing the nurturing and engagement of human capital within the SAF.

7 NURTURING OUR PEOPLE IN IKC2 COMPETENCIES

"The quality of our people is the most important factor in the SAF. As we transit to a 3rd Generation SAF, we will need more able, well-trained and experienced people."

Mr Teo Chee Hean
Minister for Defence

INTRODUCTION

To achieve a 3rd Generation SAF that is integrated and networked, capable of undertaking missions in a systemic and synergistic manner, mindsets need to be changed, command and control doctrines needs to be updated, and the nurturing of our people needs to be re-tuned. Nurturing our people is the **second thrust** of our *ONE* SAF. In the 3rd Generation SAF, nurturing our people in IKC2 competencies involves not just training our people in IKC2 systems and capabilities. It also includes seeding and growing the culture of continual learning, cultivating an innovative and collaborative mindset, and infusing thinking and acting integrated into our DNA. This will nurture our people to become both **knowledge and learning nodes** within their area of work. In addition, the SAF also recognises the importance of heartware and commitment of our people. The **third thrust** of our *ONE* SAF is therefore engaging our people, to strengthen their sense of commitment and will to fight.

As we operationalise the 1st spiral of the 3rd Generation SAF, a parallel effort to nurture our people in IKC2 competencies is already underway. These efforts not only infuse IKC2 systems and capabilities, but also inculcate a stronger sense of "oneness", ensuring that our people do not view themselves and behave in a compartmentalised, Service-centric manner, but rather, as part of a larger entity.

Using Bloom's taxonomy as a framework, the nurturing of our people in IKC2 competencies will be discussed along the dimensions of **Knowledge, Skills** and **Attitude**. This article will highlight the main initiatives along each dimension, as well as identify some of the challenges that the SAF faces. A short discussion on issue of engagement will then complete a holistic picture of people development within the SAF.

DESIRED OUTCOMES

The desired outcomes from the SAF's efforts to nurture people in IKC2 competencies are as follows:

- **IKC2 Competent at All Levels.** Being IKC2 competent at all levels of command will enable and ensure the SAF leverages and exploits both intra- and cross-domains capabilities afforded by being networked. Operational Commanders will be able to better understand the complexities and operational benefits of network-centricities, thereby enabling them to exploit and assimilate IKC2 technologies into the SAF's warfighting capabilities.

- **Think and Act Integrated.** While networking platforms and systems are essential, the SAF recognises that if a compartmentalised and Service-centric mindset among our people persists, we will not be able to fully exploit the capabilities afforded by IKC2. The SAF has therefore taken steps to infuse IKC2 into the DNA of our people through integrated training – bringing people from the different Services together for IKC2 training, not just in the physical but also virtual/cyber domain.

- **Innovative and Collaborative Mindsets.** Beyond the tried and tested, our people should be nurtured to become thought leaders, to embody a more innovative and creative spirit. This is to facilitate growth in new and fresh ideas/doctrines in the application of IKC2. Besides this, a collaborative mindset will also be needed so that new lessons learned are quickly shared to shorten the learning curve of the SAF.

- **Continual Learning.** With the rapid advances and changes in technology, new knowledge and skills are being constantly added to the repertoire of IKC2 competencies. As a result, learning has to be continual. To encourage continual learning, positive and self-directed learning attitudes have to be reinforced. This also helps to ensure that personnel within the SAF are constantly kept abreast of technological developments and to exploit any opportunities afforded by these developments.

"This (3rd Generation) transformation will enable the SAF to be more flexible and better able to deal effectively with the range of challenges and threats in the new security paradigm, and to remain a credible deterrent and a highly effective fighting force, the SAF needs to be agile, continually adapting changing and innovative."

Dr Ng Eng Hen
Minister for Manpower
and 2nd Minister for Defence

CHALLENGES

Diverse Range of IKC2 Systems

The adoption of spiral development within the SAF has translated into a shortened concept-to-capability cycle. It has also resulted in the SAF having a diverse range of IKC2 systems in use. Combined with rapid advances in IKC2 technology, IKC2 training therefore has to address the diverse range of IKC2 systems training, and also the rapid changes in syllabi and content.

Digital Natives versus Immigrants

Today, the SAF comprises people who belong to either the Digital Natives, (i.e. people who have grown up in the digital era) or the Digital Immigrants (i.e. people who grew up in an earlier time, but are assimilating into the digital era). The learning abilities, attitudes and experiences of these two groups are different. While the Digital Natives will form the majority over time, the current division illustrates the need for IKC2 training contents and delivery to be customised to ensure optimal training outcomes.

> *"Transformation and maintaining our strategic edge lies not just in technology and concepts, but also in the quality of our leaders and soldiers. Technologies and systems are only as good as the people who operate them."*
>
> Mr Chiang Chie Foo
> Permanent Secretary (Defence)

A MULTIFACETED APPROACH

To overcome these challenges, a multifaceted approach has been adopted to nurture our people in IKC2 competencies. In essence, the approach will address the following areas:

- **Knowledge**. This involves the use of courses and formal learning sessions. Such courses are also important in tracking the developmental milestones of personnel within the SAF, to ensure that they fulfil the necessary requirements within their careers.

- **Skills.** This involves learning through "doing". Through "doing" and "hands-on", a person is able to internalise his learned knowledge, and improve on the skills required of him.

- **Attitude.** This is about inculcating a learning culture, enhancing our people's capacity and propensity to learn new things.

Knowledge

Courses in IKC2 are conducted at every major stage of a person's career, both at the Service level as well as at the SAF level. In addition, SAF also collaborates with commercial and tertiary institutions for up-to-date C4IT programs, including postgraduate studies. This ensures that our people, including SAF senior leadership, are constantly attuned with IKC2 developments within the 3rd Generation SAF.

IKC2 Courses for SAF Senior Leadership

The senior SAF leadership attends IKC2 courses and is always kept current on the latest technological developments. This has enabled them to possess a common language with their staff. Hence, they are able to drive IKC2 system developments as well as doctrines and processes with greater knowledge and clarity. In the Army, the top leadership groups also take the examinations and assessments that are part of the course, further strengthening the notion that the SAF is serious about nurturing IKC2 competencies.

SAF's Top Leadership Attending an IKC2 Course

Career Courses

Courses such as the Basic Military Technology Appreciation Course in the Air Force are pegged at entry-level knowledge while courses such as the Diploma in Defence Technology and Systems (DDTS) or the Advanced Military Technology

Appreciation Course (AMTAC) cater to personnel later in their careers. At the SAF level, officers from three different Services are trained together in IKC2 subjects. Here, they build a common understanding of command system functions and a common technological language to communicate with. In integrated exercises, the three Services of the SAF work together to strengthen their unity and their ability to coordinate with each other.

C4IT Programs

Courses to train our people include commercially available C4IT programs as well as those offered in suitable tertiary institutions. This not only opens up new learning opportunities, but ensures that the military is constantly benchmarking itself against its commercial and industrial counterparts. In the SAF, a good example is Signal Institute, which has partnered several polytechnics to offer C4IT programs for our people. Recognising that networking plays a crucial role in IKC2, it has also been an accredited CISCO Academy since 2004 and has since qualified more than 2,000 CCNA 1 and 2 graduands combined. As these courses and certifications are valid for only a few years, one has to regularly retake them to maintain competence in that field. These regular exams thus require our people to constantly upgrade themselves, making lifelong learning a prerequisite for success and usefulness within an IKC2-centric SAF.

Postgraduate Studies

To build up deep specialised knowledge in IKC2-related areas, selected personnel are sent to pursue postgraduate studies in fields that are relevant to the prevailing trends within the SAF, in order to sharpen their technical competencies and technology management skills.

Skills

Besides imparting knowledge, nurturing our people in IKC2 competencies also includes training and equipping them with the skills to establish and operate IKC2 systems effectively. To do that requires a "doing" and "hands-on" approach. The SAF actively nurtures our people in IKC2 skills through learning from operations, exercises, projects and simulations.

Operations and Exercises

Operations provide the real life scenarios that enable our people to put into practice what they have been trained to do as well as to acquire new skills. In OFE, the largest relief operations undertaken by the SAF in 2004, the SAF learned invaluable lessons such as working as a Joint Task Force, and how to interoperate with civil agencies and the media. As a Joint Task Force, the SAF was able to take integration and networking procedures and processes to the next level. For example, the development of Quick Deployable Command and Control (QDC2) equipment after OFE enabled quick communications deployment as well as interoperability with civil agencies. Through these operations, the SAF's competencies in Operations Other than War (OOTW) missions are greatly enhanced.

Aside from operations, exercises enable our people to experiment with new system fighting capabilities, new doctrines and new processes. These exercises, such as Ex. Forging Sabre and Ex. Wallaby, employed meaningful slices of system capabilities to deliver effects greater than the sum of its parts. For the operational community, they are able to re-design command and control processes with the infusion of IKC2. For the C4 community, they learn about how to enhance the system capabilities; their learning curve is greatly shortened with the presence of DSTA, DSO, Singapore Technologies and other local defence industry agencies at these exercises, providing technical advice and expertise for systems that are being employed. Such an arrangement also fosters greater Ops-Tech Integration in systems development. In Ex. Forging Sabre, such training also strengthened greater integration between the Air Force and Army, as they had to work together to network both the Air as well as ground platforms. This not only fostered the exchange of knowledge, it also allowed both Services to understand each other's processes and procedures.

Project-Based Learning

Another avenue of skill development is in project-based learning. This can encourage innovation, collaboration and self-directed learning. Projects are undertaken in specific IKC2 areas, allowing for project members to learn through a "hands-on" experience. The lessons learned from these projects can then be shared at a wider forum to encourage greater interest in IKC2 developments. One such initiative already in place is Project Digilink, undertaken by Signal Institute. Project Digilink provides funding for any IKC2-related research, and outstanding projects are regularly evaluated, with some translated into new teaching material to continually enhance the training curriculum.

Attitude

A third aspect in the nurturing process is the shaping of our people's affinity towards learning and self-improvement. The SAF champions the qualities of a keen learning organisation and it is important that our people leverage on this quality. The following are several initiatives:

Learning Organisations

The SAF has invested resources to equip our people with Organisational Learning tools such as Personal Mastery, Shared Visioning, Mental Models, Team Learning and System Thinking to strengthen the learning capacity of our people. An example of such tools, the Three-Legged Stool, is explained below. These tools bridge the difference in learning needs and styles of different people towards organisational excellence. In doing so, those with new knowledge and those with wisdom can create a collective pool to draw upon for new ideas and novel uses of IKC2 tools.

The Three-legged Stool

The stool is a metaphor of the core learning capabilities (aspiration, generative conversation and understanding complexities) that will help the organisation build the capacity to create the future or the results that it truly desires.

The Learning Army initiative was started in 2001. This is an important effort to catalyse partnerships in IKC2 training. Over the last few years, the Army has consciously incorporated qualified National Servicemen Full-Time (NSFs) to partner the regular corps in experimenting, fielding, documenting and sharing how new networking technologies can be used to enhance IKC2. The Air Force has established an Organisational Development (OD) framework anchored on Organisational Learning (OL), Knowledge Management (KM) and Leadership Development (LD). This will guide the RSAF towards its vision of becoming a first-class learning organisation. The Navy has also embarked on its Knowledge Management journey to transform the Navy into a Knowledge-Centric Navy.

Continuous Learning

In line with the national policy of continuous life long learning, the SAF has also ensured that learning is the bedrock of our nurturing process. Such initiatives include:

- **Active Learning.** The inclusion of discussions, debates and the analysis of case studies, so that learners are more familiar and confident in applying what they have learned.

- **Problem-Based Learning.** In line with Knowles' theory on andragogy, problem-based learning has been introduced in many SAF Institutes as part of IKC2 training, leveraging on real-life examples from past exercises. Such pedagogy should become the norm of training delivery in the long run. This will ultimately mean empowering our people in structuring their own learning and creating relevant curricula for them to discuss.

> *"We all appreciate that transformation to the 3rd Generation SAF cannot only be about hardware and software. With money, we can buy the hardware. With brains and determination, we can develop the software. But what is most critical is to build the heartware and commitment of our people."*
>
> LG Desmond Kuek
> Chief of Defence Force

ENGAGING OUR PEOPLE

Through IKC2 capability development within the 1st spiral, and the nurturing of IKC2 competencies among our people, we enhance the **Hardware** and the **Software** of the SAF. A third facet, the **Heartware**, is an equally critical component. Only systems and technologies multiplied by a strong will and commitment to fight for the larger cause will bring about a superior fighting force. The aim then, under the **third thrust** of the *ONE* SAF, is to engage our soldiers, sailors and airmen, and instil in them commitment and pride.

This section briefly touched on two areas of engagement, specifically in the area of nurturing IKC2 competencies: the first is on engaging our largely NS populace; and the second is on role modelling.

Recognising Our Quality NSFs: Trainees to Trainers

There is a Chinese saying that "although the student's knowledge is borne from his master, over time the student will exceed his master". Similarly, in many technical aspects, a young person's ability could far exceed that of his predecessors. The SAF views the aspect of knowledge from the perspective of a flat hierarchy; rank or experience is not a limiting factor.

As the younger generations possess the technical know-how and capability, it would be useful for them to share their knowledge with the older generations. Being fresh graduates out of junior colleges, polytechnics or universities, they would be well-versed in the latest technologies that may be applicable in the SAF context.

One way is to adopt the trainee-as-trainer approach where well-qualified trainees are engaged to share their knowledge with their instructors and their peers in certain technical subjects. For example, in Signal Institute, trainees with the relevant technical qualifications are identified and taught basic instructional skills so that they can conduct Cisco-certified Network Associate (CCNA) and Cisco-certified Network Professional (CCNP) networking courses for their peers. This ensures that the NSF have a positive NS experience and feel gainfully employed. They will also become more receptive to learning and ensure that the sharing of new technologies can be applied in the military context.

Role Modelling: Leadership by Example

From a social cognitive perspective, observational learning plays a large role in creating and sustaining a positive learning environment. By observing others and the repercussions of their actions, a person's behaviour changes. When learners are then given the chance to model such positive behaviours, these behaviours are reinforced and propagated through the Army.

Sociologist Robert K. Merton emphasised the importance of the role model. Thus, to catalyse the change and to spur the older generation past that learning tipping point, it is important for high-ranking officers to lead by example. When the top leadership embarks on re-profiling courses, they set a precedent for others to also go for courses to acquire new skills and knowledge.

MOVING FORWARD

IKC2 will undoubtedly bring great change and improvements to the SAF. As one of the key enablers in realising the 3rd Generation SAF, IKC2 plays a pivotal role in enabling seamless command and control on the battlefield. By building a connected framework for various systems to seamlessly inter-operate, SAF will be better positioned to respond and deal rapidly with constantly changing conditions and threats.

However, to be absorbed or interested in developing and implementing state-of-the-art systems, independent of a consideration of the SAF's human resources, would be short-sighted. We must complement such a system with an equally able, technology-savvy fighting force.

To realise the full potential of the new fighting system, we must leverage on new education paradigms to nurture the IKC2 competencies in our people. Not only that, we also need to understand the inherent differences in learning abilities of our people and leverage on their unique strengths, while mitigating their imperfections. However, implementation of new learning techniques and thinking styles will not suffice in optimising our human resources for IKC2. The transformation in learning is an ongoing journey, not a destination.

The process of nurturing IKC2 competencies is flexible, self-sustaining and strives to be exciting and relevant. Such training will create people who are able to function at a high level with regard to IKC2, understand the systems used and use them appropriately. There is also the need to engage our people, ensuring that they possess the commitment and dedication to the cause of the SAF. It is only when we fuse our capability development with the nurturing of IKC2 competencies and the engagement of our people, will we be able to move towards being a 3rd Generation SAF.

ENDNOTES

1 www.mindingtheplanet.net

2 IKC2 was conceptualised as a network-enabled, knowledge-based warfighting concept that is predicated on the OODA loop. IKC2 aims to exploit C4IT technologies to ensure that not only does one's OODA operate faster than the adversary's, but also that we are able to effectively disrupt the adversary's OODA cycle.

3 An example would be the use of combat models based on Lancaster equations Model.

4 For instance, the famous Deep-Blue computer from IBM did not have any intelligence of its own, and it could not autonomously develop its mental abilities over time.

5 Ongoing research in Nanyang Technological University (NTU) is trying to establish the "blueprint" of human intelligence.

6 Dr David Alberts in his article "Future of C2" argues that the future of C2 is not C2 and posits a new frame and definition of "Agility, Focus and Convergence".

7 Conforming more towards Reeds Law.

8 Sensemaking is a process that builds *deep understanding* of a situation in order to deal with that situation more effectively through better judgements, decisions and actions.

9 This includes *social complexity* as opposed to merely mathematical complexity.

10 Carl von Clausewitz, *On War*, 2007.

11 Carl H. Builder, Steven C. Bankes and Richard Nordin, *Command Concepts*, 1999.

12 Van Creveld, *Command in War,* pp151-152.

13 Van Creveld, *Command in War,* pp268-275.

14 William R. Ashby, *Introduction to Cybernetics*, 1964.

15 Richard Bellman, *On the Reduction of Dimensionality*, 1961.

16 Computational power = o(time^2), demand = o(d^entities)

17 James Moffat, *Complexity Theory*, p46.

18 A.-L. Barabási and E. Bonabeau, "Scale-free Network", pp60-69.

19 Divisions, Brigades, Battalions, Companies and Platoons.

20 Fire support, intelligence collection asset, engineering, logistics, etc.

21 Such as the types, expected numbers and probable locations of the targets.

22 Mark Buchanan, *Ubiquity*, pp67-81.

23 Barabasi, *Linked*, See research work on self-organised criticality, sand-pile theory.

24 With a $6.8 billion price tag, is JTRS out of reach? (2006). See http://rfdesign.om/military_defence_electronics/news/jtrs_out_reach/

25 R. Zafalon, "Low Power Design for Embedded Systems" at 6th International Conference on ASIC.

26 http://www.mitre.org/work/tech_papers/tech_papers_01/cokus_vocablulary/index.html

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