Prototype Warfare, Innovation and the Fourth Industrial Age

Peter Layton

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Foreword

The emerging fourth industrial revolution is based on continual – one might say relentless – innovation. Australia has already begun embracing the revolution across government, industry and academia. An early tangible sign is the standing up of an Australian space agency.

This latest revolution is so all-encompassing that it will not pass Air Force by, but this is to our advantage. The fourth industrial revolution can make Air Force considerably more agile by providing a robust pathway to prototype warfare. Such an approach can bring innovation deep into Air Force making us more effective in the contemporary environment of ongoing rapid technological and geo-strategic change. Less immediately obvious, but also important, is that the fourth industrial revolution can potentially bring marked improvements to our logistic support activities and our ability to mobilise in times of crisis.

The fourth industrial revolution, however, is not easy to implement. It involves Air Force getting closer to industry, research facilities and academia, but directly, not through outsourcing our connections. Moreover, the defence marketplace may experience change as small-medium enterprises become increasingly important while new defence industry entrants are empowered. Lastly, and most personally, a culture of innovation will need embracing by all across Air Force. Traditionally, military forces have found this difficult but it is essential. Innovation cannot be created on command but instead requires deeper, more fundamental engagement by all.

Dr. Layton's paper explores the fourth industrial revolution and its implications for Air Force. While gradual, the revolution will impact us all, not just at work but at home as well. This paper continues the theme begun in 2017 by *Beyond the Planned Air Force* of starting to think about how Air Force and warfighting might change in the medium-long term. The fourth industrial revolution has arrived on our shores. How we can best exploit it deserves considerable thought.

GPCAPT Andrew Gilbert
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Introduction

In 1993 American futurists Alvin and Hedi Toffler published a book arguing that a new way of war was emerging. They postulated that developments in information technology would lead to so-called 'third wave' warfare where knowledge was central. This insight was based on a very simple premise: "the way we make war reflects the way we make wealth".[1] It was also not a truly novel thesis. Scholars working in the Marxist tradition had been saying something broadly similar for more than a century.

Nevertheless the Tofflers were right. Information technology did revolutionise warfare and at a remarkable speed. Indeed, third wave warfare has been steadily accelerating, reflective in itself of Moore's law that highlights the exponential growth in recent decades of computer processing power. As the Tofflers observed though, the world is a heterogeneous place.

There remain pockets of first wave warfare based on agrarian economic principles. Moreover, some nations still cling to second wave warfare based on the industrial revolution, albeit with Saddam Hussein's mechanised land forces comprehensively destroyed in Gulf War One there is now one less. The leading edge of warfare now is all about knowledge. Brains can now defeat brawn, and startlingly easily.

Historians are often appalled at such gross simplifications as three wave warfare. However, people find such approaches an easy way to give some order and structure to large-scale historical events. The 'fifth generation warfare' term coined by the Royal Australian Air Force is

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1 Alvin and Hedi Toffler, 1993, *War and Anti-War: Survival at the Dawn of the 21st Century*, Boston: Little, Brown and Company, p.3.

just another example of the cognitive appeal of simplifying moves. Now, though, there is another such move entering the lists and this may give us some useful pointers to the future.

In recent years German engineer-economist Klaus Schwab has been actively popularising the idea that we are now entering the fourth industrial revolution.[2] Industrial revolutions attract attention as they are periods in which fundamental innovations lead to wholly new ways of doing things, not just simply efficiencies or lower production costs. Schwab's claim, like the Tofflers, is not completely novel. Industry 4.0 has been discussed in Germany since 2011, however the idea has now gone global.

Hard-nosed businessmen and women, governments of all persuasions and numerous countries across the world are taking the fourth industrial revolution notion very seriously. The concept is being progressively incorporated into national industrial plans, including across Europe (Germany, UK, Netherlands, Spain, Italy, Sweden and France), in North America (US, Canada and Mexico) and in the Indo-Pacific region (China, South Korea, Japan, Taiwan, Malaysia, Singapore and India).

Australia has also recently embraced the fourth industrial revolution with a strong government push to help Australian companies, research facilities, education providers and academia get involved. As an example, the recent creation of an Australian space agency is linked to the Federal government's fourth industrial revolution ambitions.

The perceived latest industrial revolution's numbering sequence fits well with the Tofflers' historical classifications as this fourth step in Schwab's schema builds on the information technology revolution. The fourth industrial revolution is seen as encompassing a dizzying array of technologies including data analytics, the Internet of Things, additive

2 Klaus Schwab, 2016, *The Fourth Industrial Revolution*, Geneva: World Economic Forum.

manufacturing, robotics, cloud computing, artificial intelligence and cognitive technologies, nanotechnology, biotechnology, advanced materials, augmented and virtual reality.

Some bracket many of these technologies together under the term cyber-physical systems to highlight that in the fourth industrial revolution they are all tightly interconnected. For the defining characteristic of the new revolution is not a particular technology, but instead connectivity. To drive the point home, some say hyper-connectivity as it is much deeper and broader than that connectivity we are so familiar with in the third industrial age, and by extension in third wave warfare. This intensified connectivity creates the 'prosumer', another term created by the Tofflers.

The impact of the fourth industrial revolution on preparing for, and waging war, is explored across this paper. Suffice to say here that the fourth industrial age continues the third industrial age in bringing more power to the individual. Each of our personal smart phones today has more computing power than existed anywhere in the second industrial age. This gives us each access to information, data, imagery, video streaming and global voice services undreamed of even a decade ago.

The fourth continues this trend but now connects us to the factory, the research facility and academia so that we can all potentially individually design, produce and test hardware and software innovations - and fix them when they break. In the fourth industrial revolution one-off unique items can now be affordably manufactured. The term 'prosumer' reflects this, being a combination of pro-duction and con-sumer.

These advances have multiple implications for the making of war, and even, perhaps, its definition. As has been historically common, the character of war is today changing as new technologies such as robotics, big data and cloud computing are embraced by militaries worldwide. Moreover, there also seems a shift in war's very nature underway as computing advances like artificial intelligence allow engaging individuals on their personal devices in precisely targeted approaches that influence their thinking and in aggregate divide the nation. Such cognitive warfare seems very remote from the clash of colourfully uniformed armies Karl von Clausewitz wrote about in his seminal 'On War'.

This paper, though, takes a different tack from such debates and instead looks at what the fourth industrial revolution means for military innovation. If the character and nature of war are changing, militaries need to become innovative and also change - or risk becoming irrelevant to the societies they protect. This is a traditional line of argument but there is a new twist.

Innovation itself is the essence of the fourth industrial revolution. If "the way we make war reflects the way we make wealth" then a fourth industrial revolution military must inherently be an innovative one. The word 'innovation' means to make changes in something established by introducing new methods, ideas or products; it is derived from the Latin *innovare,* meaning 'renewed' or 'altered'. Such meanings when applied to military matters immediately suggest difficulties.

Resisting change is in many respects in the DNA of military forces. They are deliberately designed to be hierarchical organizations that endure and perform regardless of the intense operational stresses and strains placed on them. It has become commonplace for people to assert that militaries are always preparing for the last war and so always fail to innovate in a timely manner for the next conflict. Regardless of the veracity of that popular belief, the fourth industrial revolution now compels militaries to innovate, not just to avoid impotence or irrelevance in a new technological era, but primarily because the fourth industrial revolution is all about innovation itself, as this paper will discuss.

Unpacking the 4IR Idea

The fourth industrial revolution (4IR) is the product of what went before. In the 1760s the first industrial revolution created steam powered engines that mechanised production and transport. Military forces started using manufactured - not handmade - equipment and deployed by rail rather than on human or animal foot. In the first half of the 20th Century the second industrial revolution introduced steel, sophisticated chemistry and electricity. Military forces on land and at sea quickly mechanised and air power became a dominant battlefield actor; it was the age of mass production, machine wars. In the second half of the 20th Century, the third industrial revolution arrived ushering in electronic and digital computer technology that rapidly became more powerful and much smaller. Military forces now embraced smart, precision-guided missiles, automated command systems and space-based systems; the battlefield emptied as firepower dominated.

In the early 21st Century, a fourth industrial revolution is building around four key drivers:

1. Significant growth in the volume of data available, the computational power to assess 'big' data and widespread, high-capacity connectivity.
2. Much enhanced data analytics and business-intelligence capabilities including the use of artificial intelligence.
3. New forms of human-machine interaction, such as robust touch interfaces, augmented and virtual reality systems.
4. Improvements in transferring digital instructions to the physical world, such as robotics and 3D printing.

These advances allow the close integration of disparate physical and digital technologies, in effect interweaving the second and third industrial revolutions and in so doing creating the fourth. Such integration now allows a continuous and cyclical flow of information and actions between the physical and digital worlds. These two worlds of the second and third industrial revolutions are no longer separate but deeply intermeshed in the 4IR's physical-to-digital-to-physical (PDP) loop that encompasses:

1. **Physical to Digital**: Capturing information from the physical world and creating a digital record from physical data.
2. **Digital to Digital**: Sharing information and uncovering meaningful insights using advanced analytics, scenario analysis, and artificial intelligence.
3. **Digital to Physical**: Appling algorithms to translating digital-world decisions to prompt action and change in the physical world.

Such a loop allows ongoing learning, permitting continual adjustment of the process in near real-time. The 4IR is therefore not simply a further development of the third industrial revolution, but instead something new.

Many organizations already have some physical-to-digital and digital-to-digital processes but it is closing the loop from digital back to physical—that is, acting upon analysed data and information—that marks the big technical advance. This positive feedback loop means that the 4IR is evolving at an exponential not a linear pace, is disrupting almost all industries and is having an impact on the whole global economic system and most of its people. The 4IR combination of digital and physical technologies means change is "happening ten times faster and at 300 times the scale, or roughly 3,000 times the impact" of the first industrial revolution.[3]

Implementing such a loop that crosses multiple physical and virtual domains and operates through time from the initial innovation to product disposal is not easy. It requires combining a range of particular physical and digital technologies that vary with the circumstance, but which can include data analytics, the Internet of Things (IoT), additive manufacturing, robotics, high-performance computing, cloud computing, natural language processing, artificial intelligence and cognitive technologies, nanotechnology, biotechnology, advanced materials, augmented and virtual reality.

In the 4IR vision, the ideal PDP loop would involve consumers across the world passing their demands on the Internet to a global automated coordinating centre. The coordinating centre would then instruct manufacturing enterprises dispersed around the world to undertake production where and when required. Consumers would supervise the complete process including design, production, transportation and post-sale maintenance support through the Internet. Under the ultimate 4IR there would be a single unified global market.

This vision highlights that the 4IR aims to have significant impact at both the individual and system level. At the individual level 4IR will sharply empower 'prosumers', defined by the Oxford Dictionary as a consumer who becomes involved with designing or customizing products for their own needs.[4] The prefix 'pro' then relates to

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3 Richard Dobbs, James Manyika, and Jonathan Woetzel, 2015, 'The four global forces breaking all the trends', *McKinsey&Company*, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-four-global-forces-breaking-all-the-trends [Accessed 5 December 2018]

4 Oxford English Dictionary, 2018, https://en.oxforddictionaries.com/definition/prosumer [Accessed 12 December 2018]

production with 'sumer' to consumer. At the system level, the 4IR's system is much deeper and broader than under the third industrial revolution and is accordingly better viewed as an ecosystem: a complex network of diverse and dispersed human and machine entities that continually interact with each other and their environment.

Prosumers

The 4IR aims to sharply lower the barriers between innovators and markets. The innovator can design their one-of-a-kind, requirement-optimised product on the internet, pass this to the organisation undertaking production and negotiate delivery costs and schedules. With techniques like additive manufacturing[5], the production batch sizes can be very small or on-demand without any significant impact on production efficiency. Moreover, with the internet-of-things, the entire product lifecycle can be monitored and controlled. A product can now seamlessly move from innovator to production to delivery to consumer with no human intervention or involvement.

Within this process are two noteworthy aspects. Firstly, the process readily allows rapid prototyping, testing and product improvement (albeit this is a latent possibility only). Moving to embrace a rapid prototyping concept depends on each organisation's imperatives and their receptivity to innovation. Company structures and cultures can combine to resist the potential gains the 4IR offers.

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5 3D printing, or additive manufacturing, is a technology that creates a three-dimensional shape by printing layer upon layer as guided by a digital three-dimensional drawing or model. In contrast, traditional subtractive manufacturing technology produces a desired shape by removing layer by layer from a piece of material. 3D technology encourages innovations through offering unprecedented design freedom. Moreover, there is no longer a need for any specific tooling for manufacturing, avoiding manufacturing setup and tooling costs. *The Free Beginner's Guide*, 2016, 3D Printing Industry https://3dprintingindustry.com/3d-printing-basics-free-beginners-guide [Accessed 12 December 2018]

Secondly, maintaining large stockholdings of products or logistic support items is not necessary. They can be produced quickly when needed years after the initial product development and production. Such a surge capacity for military forces is particularly so if the parts are designed under the 4IR framework allowing the use of commercial general-purpose advanced manufacturing facilities, not solely defence-specialised plants (this mobilisation dimension is discussed further later). Importantly the 4IR PDP loop means deployed products can be continually monitored and automatically replaced, or have maintenance components and logistic support items made and delivered to the product user just-in-time.

Eco-system

The 4IR moves beyond the realm of manufacturing and production to focus on the entire ecosystem of innovators, partners, suppliers, customers, workforce, product users and operating environment. The earlier industrial revolutions stopped at the factory door but the 4IR moves considerably beyond. The 4IR enables the smart factory, connecting it into the earlier-stage design and later-stage logistics networks allowing all stakeholders to be much better informed than previously. Information from the interconnected networked systems can enable companies and their partners to offer much enhanced post-sales support to customers, effectively bringing the customer deep into the factory. This is a vision of hyper-connectivity considerably broader and deeper than that in the third industrial revolution.

Implementing such hyper-connectivity on a large scale will require the emerging 5G communications network. Compared to older networks, 5G offers enhanced mobile broadband, massive machine-type communications, and ultra-reliable and low latency communications. The mobile broadband improvements will expand augmented and virtual reality applications. The machine-type communications will considerably improve the IoT, the network that will link diverse geographically-remote products into the ecosystem, and the connection of many different kinds of smart devices, sensors and industrial equipment. The ultra-reliable, low latency communications are needed for mobile robotics including autonomous vehicles, mission critical applications where safe operation is crucial, and tactile applications such as remote surgery. 5G is a crucial enabler of the 4IR but brings with it some significant geo-strategic implications as noted in the next chapter.

In considering the 4IR hyper-connected ecosystem there are three notable aspects. First, while individual technologies are interesting, it is their impact on the overall ecosystem connectivity that matters. Organizations need to take a holistic view of the 4IR and the ways in which it may change their business practises.

Second, innovation in the 4IR can involve simultaneous interactions with entities of many different types, sizes and locations. In the earlier industrial revolution there was a much more linear process where innovations were sequentially ‘handed off’ from one well-defined part of the product lifecycle to another but no more.

Third, the ecosystem does not just happen. Instead it is created by purposeful action to put in place connections and data linkages. Moreover, the ecosystem requires ongoing maintenance in the sense of sustaining machine-to-machine communications but also in terms of governance in ensuring standards are both set and followed by all. The 4IR is a future by design not by happenchance. It is agency writ large.

Preparing for War in the 4IR

The defining characteristic of the 4IR is not a particular technology but instead an intense connectivity. This characteristic creates both the prosumer and the ecosystem that when combined allow continual broad-based innovation and its rapid, global diffusion. Such connectivity though has its shortcomings, raises concerns and creates vulnerabilities.

A Prosumer Force Structure

The customer is now at the core of the production process. Under the 4IR customers will be able to adjust order specifications not only before orders are placed but also during design, manufacturing, assembly, and testing. For the warfighter this means that they can be deeply involved in customising their physical equipment and cognitive support to be optimal for their needs and operating environment. Moreover, this flows through from the design to the in-service phase where warfighters can readily implement reliability improvements and carefully plan to achieve on-time logistic support.

Such a process equally applies to software development. Warfighters could be deeply involved in the creation of new algorithms and their continual adjustment to best-fit operational circumstances. This may be especially so with artificial intelligence that being 'learning machines' can greatly improve their performance through timely human correction and advice. In this way, artificial intelligence can learn on the job from experienced warfighters.

The 4IR then offers an enticing vision of a defence force structure that is continuously evolving to best meet emerging operational demands. With a 4IR process, the time lag between new challenges arising and appropriate technological responses being introduced into service can drop dramatically. Continual innovation will be the dominant quality of the future force structure in the 4IR era.

In this there are issues. There will be no force structure baseline except in digital model form. Ideally the continuous evolution process will include assessing how the new customised equipment the warfighter is designing will integrate doctrinally and technically with the rest of the joint, interagency, combined force. This will not be easy given the rest of the force elements are also continually evolving. The warfighter will need to collaborate when innovating not just vertically with 4IR capable factories but also horizontally with other military units, governmental organisations and allied defence forces.

In the industrial domain, the 4IR is forcing companies to move from using linear, sequential business operations towards deeply interconnected, open systems that stress collaborative processes. Today the traditional supply chain steps through planning-developing-sourcing-making-delivering-supporting. Under the 4IR, this linear progression changes to a circular one with a digital core where the elements of connected customer/synchronized planning/ digital development/ smart factory/ dynamic fulfilment and intelligent supply all concurrently interact. Defence forces will also need to move to such dynamic open systems and processes to gain the full benefits of 4IR's continual innovation.

There is a further issue for military forces with their traditional hierarchical command structure in embracing continual innovation. The question arises of where should the prosumer be located? At its core this is a question of whether innovation should be centralised or de-centralised. Ideally in the 4IR model it would be at the tactical level where the competition is hardest and its parameters most apparent. There are, though, arguments that innovations need to be considered from a whole-of-force perspective rather than from an in-the-trenches view, that tactical units could have a somewhat myopic outlook. Such an argument considers that the 'consumer' is not the tactical units but rather the force as a whole. There are obvious compromises such as authorising different levels of a military force to be able to undertaken innovations only within well-defined boundaries. However, the issue of who the prosumer is will need careful thought as it potentially could significantly limit 4IR gains.

In all this there will be some drag from the existing force structure. It will be easier to customise existing equipment and devise new equipment that fits within the extant force structure parameters. The notion of 'plug and play' will have considerable appeal. This appeal will be both at the level of the individual user where retaining the current interface reduces the need for retraining, and at the system level where fitting seamlessly into the overarching command and control system lessens the complexities changes induce.

Putting the Pro in Prosumer

In the production side of the prosumer there are also benefits and issues. The 4IR digital factories with their high connectivity and strong collaborative focus can significantly accelerate the production process. The German company Siemens is in the leading edge of 4IR companies. It asserts that 4IR shipyards through the integration of physical and virtual production: "can build two and a half ships in the time that a traditional shipyard can build one."[6]

Such production advances make use of two particular 4IR concepts: the digital thread and the digital twin. The digital thread runs from start to finish, connecting the entire design and production process with a seamless strand of data that stretches from the initial design

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6 *The Future of Manufacturing: Industry 4.0 is upon us*, 2018, Siemens, https://corporate.siemens.com.au/en/home/about-siemens/core-topics/future-of-manufacturing.html [Accessed 4 December 2018]

concept to the finished product. Changes to the design are then instantly transmitted across the whole process eliminating errors previously associated with slow to amend paper diagrams.

The digital twin is a model of the product that gives insights into the inner workings and operation of the product, simulates possible scenarios, and aids understanding the impact of changes. This twin runs across the value chain from product inception to service allowing later operating experiences and data to be fed back into the digital model to update it and prompt possible production changes. Thyssenkrupp Marine Systems Australia chairman John White observes that such a 4IR integrated product development and support environment avoids:

> "the pitfalls of the past where data has been difficult to manage and major programs have often relied on 2D paper diagrams. With modern technology everything can be designed and tested collaboratively in a digital world before going anywhere near a prototype…. This eliminates geographical borders [and] reduces cost and waste. These digital systems use sophisticated 3D design/development/monitoring tools and an unbroken digital thread that facilitates error-free numerically controlled production, operation and support."[7]

The mooted 250% improvement in ship production speed has some significant implications. Ships are particularly complicated products; less difficult products might have their production times shortened

7 *Digital Shipbuilding Centre of Excellence to Help Seed Australia's Manufacturing Renaissance*, 2016, Siemens, https://www.siemens.com/content/dam/webassetpool/mam/tag-siemens-com/smdb/regions/australia/press/press-releases/2016/20160330-digital-shipbuilding-centre-of-excellence.pdf [Accessed 4 December 2018].

even more. This indicates that timely – even rapid – mobilisation in the event of a defence crisis might now again be possible.

In recent decades, as military hardware has gotten ever more complicated, the ability to surge their production in time of crisis has waned. There is generally only one production line and developing another would be a protracted process, as specialised tooling would first need to be made. With 4IR though, it's possible to envisage the latest 'digital twin' software model driving numerous 3D additive-manufacturing printers. Such printers are already widely in use, daily making commercial products, but with new software could move quickly to producing military equipment. This is much more complex then it may appear as 3D printers are unsuited for some manufacturing tasks. Alternative advanced manufacturing methods might need incorporating in some situations but the general thrust remains valid.

Under 4IR, mobilisation surges become a practical option albeit the associated ecosystem needs to be designed to easily allow this possibility. T.X.Hammes somewhat dramatically indicates the emerging possibilities:

> "advanced manufacturing particularly robotics, task-specific artificial intelligence, and 3D printing will [allow mass production numbers again]…. Today a carbon 3D printer can print 100 small drones per day. As 3D manufacturing facilities grow to 100 printers that could mean 10,000 drones from a single plant PER DAY – from a single plant. UPS has announced plans for a plant with 1,000 printers."[8]

8 T.X.Hammes replying to '12. Prototype Warfare', *Mad Scientist Laboratory*, 18 December 2017, http://madsciblog.tradoc.army.mil/12-prototype-warfare/ [Accessed 7 December 2018]

The surge possibilities highlights that a feature of the 4IR is that manufacturing may occur anywhere. The manufacturing machines used can be connected to the ecosystem and receive their instructions through that. Production lines can be widely dispersed to be either near the prosumer, transportation hubs or for survival in case of attack. Such production lines, of course though, still need to be supplied the requisite raw materials.

Implicit in this is that 4IR manufacturing can occur across the globe given adequate connectivity. Mobilisation manufacturing surges can move beyond being undertaken purely within national boundaries to being undertaken globally. The key now becomes not the labour to work the factories but rather the capital to set up connected digital factories employing robotics, advanced manufacturing techniques and artificial intelligence. Capital provides the necessary productivity through acquiring machines allowing wealthy countries to overcome their inherent labour shortages and mass-produce items within their geographic boundaries.

The mooted speed of 4IR production further suggests products getting to market sooner and into the warfighter's hands much faster than currently. However, this also indicates that production in the 4IR factory might be somewhat erratic and episodic. This has some benefits in that public spending is often 'stop, go', comparable to the 4IR cycle. It also means, though, that continuous builds of equipment where employees become highly skilled at making certain items over time are unlikely in the future. In some respects this reflects the nature of the 4IR.

In the earlier revolutions manufacturing had an artisanal quality characterized by tacit knowledge and a high level of competence that employees developed through imitative learning on the job. The 4IR knowledge though is contained within the digital thread and digital twin, not within humans. The manufacturing process in being digitized is now highly formalized. There is no longer need for an individual's artisanal prowess.

The 4IR production process might be more complicated than the process used in early industrial revolutions but does not require as highly skilled workers. The digital avatar of the item being produced is the real director of the production process with its highly detailed instructions provided on call to all the production line staff through diverse digital media including tablets, virtual reality and augmented reality. This allows the linearity of the traditional production process to be sidestepped. Employees can now work across the item being created with different skills and roles working together simultaneously, all coordinated and connected through the digital thread. This overall approach is compatible with the contemporary 'gig economy' business practices that hires staff as needed and dismisses them when the piecework is complete.[9]

The peculiarities of the 4IR production line suggest that prosumers should endeavour to devise new innovations that best exploit the mode of production. Warfighting innovations that can be rapidly produced on the particular 3D printers used by commercial industry and thus readily available would appear favoured. Drones might be an example.[10] Such a production approach does not necessarily mean such innovations will not be complicated. 3D printers can manufacture complex sub-assemblies that using earlier techniques would have needed to be painstakingly constructed from many small parts.

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9 It should be noted that the factory floor employees turning the digital models into physical form can be considered as demonstrating human-machine teaming in the 4iR. With human-machine teaming also important in the emerging warfare styles involving robotics, autonomous systems and artificial intelligence, the factory process discussed could have more to instruct than may at first be thought. Moreover there are obvious implications for mobilisation. For human-machine teaming see: Peter Layton, 2018, *Algorithmic Warfare: Applying Artificial Intelligence to Warfighting*, Canberra: Air Power Development Centre, pp 24-30.

10 Jordan Golson, 2014, 'A military grade drone that can be printed anywhere', *Wired*, 16 April, https://www.wired.com/2014/09/military-grade-drone-can-printed-anywhere/ [Accessed 12 December 2018]

Ecosystem Dilemmas

The prosumer relies on the encompassing ecosystem to make innovation happen. This ecosystem is a particularly heterogeneous network that includes a very diverse range of human and machine members. This is a very different concept to the network-centric warfare model where the participants are generally all military. The 4IR network can include national and transnational individuals, companies, industries, communities and governments together with machines, robots and IoT devices. In a way, this menagerie becomes a real part of the national defence organisation, certainly in terms of driving innovation.

The diversity of ecosystem participants, though, draws attention to how difficult it will be to make distinctions between combatants and non-combatants. The two categories overlap to a considerable degree. On the one hand this perhaps helps military robustness in times of attack but on the other provides numerous 'soft' places to attack.

Reversing this perspective, in the 4IR there seems a wide cast of players who, enabled by the ecosystem, could join in a conflict and attack across both the physical and virtual worlds. A future conflict could then include conventional warfare involving regular state forces and also a wide array of non-state actors undertaking irregular warfare using unconventional means. Furthermore, this diversity is not just in actors but also in the means of war; these may range across the full gamut of possibilities from long-range ballistic missiles to WannaCry type cyber attacks.

Today's hybrid wars might then be the wave of the future, not some anachronistic throwback. Hybrid wars involve a great diversity of participants, are non-linear and extend in time and space; all criteria that apply to 4IR. There are echoes here of the Toffler's "the way we make war reflects the way we make wealth" thesis.

The ecosystem poses some strategic dangers. The 4IR intrinsically encourages diffusion of innovation. This process could empower future hostile non-state actors. This possibility was illustrated in Iraq where Islamic State employed a form of air power using low-cost commercially available drones modified using components sourced from the global marketplace. Moreover, the connectivity through the ecosystem can allow malevolent ideas to quickly spread. Islamic State entrapped vulnerable people through careful grooming while the Russian state sought to destabilise countries through heightening social divides and tensions. Ecosystems can potentially allow bad as well as good ideas to be spread.

There are some technical issues as well. 4IR involves extensive networking and close integration between many participants. Moreover, the required ecosystem runs across domain borders, national boundaries, complex company and bureaucratic hierarchies and life cycle phases. Having collaborative partnerships is then only practical if a single set of common standards is used. Accordingly, an agreed and shared reference architecture that provides a technical description and facilitates the standard's implementation is essential to the success of the 4IR.

In an ideal world, such standards would be agreed globally but this is unlikely. Several countries are implementing national 4IR strategies as part of an attempt to develop standards potentially suitable for global adoption. Not all will succeed and the 4IR world may well be a fragmented one with some countries using say Chinese standards and others US or EU ones. Across the globe there may be several 4IR 'islands' where various regions adopt a common standard, form so-called 'Productive Districts' and enjoy clear advantages in implementing 4IR. Given 4IR's connectivity characteristic the countries forming these 4IR islands do not necessarily need to be in close geographic proximity to each other.

The introduction of 5G will accelerate 4IR implementation but seems set to reinforce fragmentation. Huawei, Nokia and Ericsson are each leading industrial groups actively developing 5G.[11] However, Huawei's close links to the Chinese Communist Party are causing developed nations to be rather cautious about the company. It seems likely that the 4IR ecosystem will split into two parts: those using Huawei's and those using the others. Given its massive home market foundation, Huawei's 5G technologies could be lower cost. Moreover, Huawei is likely to be actively supported by the Chinese state to export into global markets.

Huawei's 5G technologies may become the standard across much of South East Asia, Central Asia, the sub-continent, Africa, South America and the Middle East, with Nokia and Ericsson selling to the remainder, mainly developed nations. Over time, the two alternative 5G networks could technologically diverge, hampering the hyper-connectivity 4IR needs. Reinforcing this, cyber-security concerns in developed nations may also hamper full 4IR ecosystem connection into Huawei-based networks.

Such fragmentation will inevitably hinder innovation. The more constrained the people and companies involved the slower innovation will become. As an example, work by the Australian National University on nanotechnologies for application in new generation mobile phones has involved participants in Australia, India, China, Taiwan and the US.[12] A fragmented 5G 4IR ecosystem may not support such diverse collaboration.

Associated with standards is the implementing technology and for the 4IR this is a comprehensive broadband digital infrastructure. This needs the traditional attributes of being a reliable and high-quality communication network, but to include the exponential increase in IoT edge devices needs to be on a substantial scale – at least compared

11 Samsung is also involved but to a noticeably lesser degree than the three noted.

12 Robert Bolton, 2018, 'Hold the phone: bendable, fast and green', *Australian Financial Review*, 1 December, p.2.

to the existing Internet. Such intense connectivity immediately suggests that cyber security is a major issue in 4IR. There is a risk after full 4IR rollout that a well-targeted cyber attack could gain control of an entire national-level industrial system. Accordingly, it would be prudent to manage and protect the 4IR ecosystem's digital network as a critical national infrastructure. If the 4IR island model was realised in the future the focus might need to expand from the national level to protecting the island's transnational 4IR broadband infrastructure.

It's readily apparent that the having the deep connectivity the 4IR demands requires considerable trust between participants. Without this, deep engagement, teamwork and collaboration are impossible. Establishing high-levels of trust is by no means easy but it ultimately forms the fundamental basis for 4IR success. Without trust, an effective and efficient ecosystem cannot be created in either the physical or virtual worlds. Today's growing concerns over industrial espionage and intellectual property theft by some large nation states considerably darkens the 4IR outlook.

The discussion of these various factors indicates that the construction of a 4IR ecosystem is not easy. While collaboration speeds innovation and has considerable practical benefits, it is often far from straightforward. For all involved in the 4IR it requires devising a suitable strategy, finding appropriate trusted partners, being deeply interconnected with others in the ecosystem, aligning business processes and flexibly responding as circumstances evolve. This is all well beyond the more traditional forms of business alliances and partnering, and consequently costly in time, people and money to undertake. It is also intellectually hard as the 4IR forces all involved to think deeply about how to make the offline and online worlds work together to achieve the required high-levels of continual innovation.

The costs and difficulties associated with the 4IR are only worth overcoming if there are adequate warfighting gains. How might 4IR impact warfighting? How could 4IR alter our current thinking? The next chapter addresses these matters.

The Emerging 4IR Way of Prototype Warfare

The 4IR idea holds that commercial success is best achieved by constantly developing innovations that surpass those of competitors in the global marketplace. Transferring this to the military domain means that strategic success is sought through continually fielding superior innovations that enhance deterrence or, if that fails, facilitate battlefield victory. In both the commercial and the military domains, however, achieving innovations continually superior to those of others is not an easy task. The array of competitors is both numerous and dauntingly diverse.

Indeed, in the last few decades the military domain has found ongoing technological innovation increasingly difficult as military platforms – whether armoured vehicles, aircraft or ships – have become remarkably complex. Platforms now take decades to develop and field and, with costs rising, few can be afforded. The 4IR though may provide a way to at least partly overcome these constraints, allowing military forces to once again undertake continual innovation.

The 4IR involves a prosumer located within a large actively collaborating ecosystem and able to readily undertake innovation through using a technologically sophisticated Physical-Digital-Physical loop. This means that single items can be produced that meet the prosumer's needs at an affordable cost, and that the prosumer can continue to refine the items. In this loop, testing plays an important role both to verify the items meet the defined needs and to aid their ongoing optimisation.

For military forces items can be tested for their operational utility in experimentation programs of varying fidelity and realism. The USAF Studies Board recently determined that "well-designed and executed experimentation campaigns are critically important drivers of innovation. Experimentation plays the largest role in innovation and is arguably the single most basic innovation driver."[13] The 4IR process is well designed to support such military experimentation activities, however the process inherently allows moving well beyond that.

The 4IR innovation process develops and uses digital threads and digital twins within an advanced manufacturing framework. This allows a hardware or software prototype developed for an experimentation program to both readily enter production and be later logistically supported. Less complex items can be developed relatively quickly under the 4IR process and even faster when designed for ease and speed of production within the advanced manufacturing framework. Such attention to detail also substantially helps later supportability.

The arrival of 4IR now allows the large-scale adoption of the prototype warfare concept. The concept has two phases. In the first, prototypes are developed and proven in experimentation programs as noted above. In the second, successful prototypes are produced in limited numbers and quickly introduced into service. The intent would be to rapidly field a variety of low-cost, less complex systems and then replace these with improved variants or something totally new on a regular basis. It may seem calling the small number of prototype systems in service 'short-life cycle capabilities' might be more accurate than the 'prototype warfare' phrase. However, the phrase nicely captures that these limited production items are rather immature and less than fully developed.

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13 Air Force Studies Board, 2016, *Report Highlights: The Role of Experimentation Campaigns in the Air Force Innovation Life Cycle*, National Academy of Sciences, p.1

Some Special Forces already use such a prototype warfare type concept but only on a tiny scale and for rather restricted purposes. Scaling up the idea for larger defence forces would see the short-life, semi-experimental items produced under the 4IR process being a small part of the overall national military force structure, augmenting the long-life, more complicated, well-proven platforms.

This idea of such a two-tier force is not unknown. Only 10-15% of the German Wehrmacht fielded innovative equipment during the 1940 Battle of France. The remainder relied on horse drawn wagons and equipment more reminiscent of World War I but well proven and trusted. This mattered little. The numerically small, technologically advanced mechanised units of the Wehrmacht quickly won the battle for the remainder to fill in behind. Such a stunning success is what the notion of prototype warfare aspires to.

There is an important qualifier here: having the potential to innovate does not necessarily lead to a force being innovative. A military force needs to have a mindset that is open to change. History has many examples of militaries that emphasised tradition over renewal and failed as a result. To be a successful 4IR military, the organisational culture needs to be receptive to the idea of continual innovation. Innovation is, as noted earlier, the essence of the 4IR.

In this, the concept of prototype warfare is based upon a foundation of purposeful experimentation. This can be usefully examined first.

The Underpinning Experimentation Activity

In recent decades experimentation was often linked to hedging.[14] The post-Cold War era was seen as particularly uncertain as the threat from the Soviet Union had vanished without another taking its place. It was suggested experimentation should take place on a broad front to provide a very diverse range of options, appropriate ones of which could be activated if a threat crystallised. The innovative equipment developed and trialled, though, was not intended to enter production simply to demonstrate capabilities and be filed away awaiting some future need.

In the 4IR prototype warfare concept, experimentation has a somewhat expanded function. Moreover the context has changed. The future is now seemingly less uncertain with at least US declarations that China and Russia are strategic competitors, North Korea and Iran are dangerous and that hostile armed non-state actors remain active across the greater Middle East. There are now several well-defined issues of concern, albeit some uncertainties remain.

Accordingly, the 4IR prototype warfare experimentation program may involve some innovations intended to provide options, and thus hedge against uncertainty, and others intended to enter limited production to meet specific short-medium term needs. However, even the hedging innovations could eventually enter production at some stage if circumstances evolve to make them useful; Stephen Rosen writes:

> "Large scale procurement is deferred…to allow uncertainties to work themselves out. When long-term uncertainties become short-term requirements, decision makers can choose from

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14 Including by this author. See Peter Layton, 2003, *Towards managing uncertainty: coupling experimentation with rapid prototyping*, Fairbairn: Aerospace Centre.

> an array of prototypes the system best suited to the needs of the day. A necessary component of this strategy, therefore, is a capacity for mobilising production from prototypes."[15]

Operators who can experiment with a prototype can more easily envisage its potential than if the concept remains intangible and theoretical. They can readily extrapolate from the experience gained in employing such prototypes. USN Admiral Cerbrowski gave an indication of this process when discussing an experimentation program using Australian fast ferries:

> When one introduces an operational prototype, when you put something in the hands of people … that can indeed be very, very powerful. And there are several examples of doing that. We have one of those going on right now with the lease of a high-speed transport ship for experimentation with the Army, the Navy, the Coast Guard and the Special Operations Forces. You also have the Marine Corps experimenting with one out in the Pacific. And already, although these ships have been in the hands of the operators for only a matter of weeks, already you can tell that minds are racing and ideas are coming forward.[16]

Experimentation with trial products provides opportunities to develop and refine new concepts of operation to fully exploit the new capability, to evolve operational requirements as experience and understanding are gained, and to operate militarily useful quantities

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15 Stephen Peter Rosen, 1991, *Winning the Next War: Innovation and the Modern Military*, Cornell University Press, Ithaca, New York, p. 245.

16 Arthur K. Cebrowski, 2001, Director, Force Transformation, *Special Briefing on Force Transformation*, 27 November, http://www.au.af.mil/au/awc/awcgate/transformation/t11272001_t1127ceb.htm [Accessed 12 December 2018].

of prototype systems in realistic military demonstrations, and on that basis, make an assessment of the military utility of the new capability.

Furthermore, with careful management, the development of prototypes can nudge and push organisations to evolve in desired directions. The butterfly effect underpinning chaos theory can be harnessed to focus the latent energies of an organisation to a point where it can self-organise into new forms. In this manner, operational prototypes can act as change agents that 'pull' organisations into the future whilst diminishing the normal internal organisational resistance.

A 'learning' organisation can be created that considers continuous innovation a normal and desirable situation. The impetus for change now comes from within organisations, rather than from impersonal external forces, as the personnel are now a central part of the experiments with the operational prototypes they have helped developed.

The prototype experimentation process needs to focus mainly on quickly addressing short and medium term needs.[17] The envisaged short in-service life of the prototype equipment would permit a correspondingly modest logistic support structure. The prototypes built would be of those new and imaginative ideas and concepts not available elsewhere. This later type of equipment could be acquired for experimentation purposes through leasing, hiring, borrowing or collaboration.

At the conclusion of the experimentation phase there are three potential outcomes. First, if the capability or system does not demonstrate military utility of current relevance, the project terminates as quickly as possible to conserve scarce resources. However, the

17 The existing major equipment acquisition system would remain focused on the longer-term needs, and especially those projects involving major platform buys. These are inevitably complex, take a long time to enter service and have high life cycle costs.

information gained will have expanded the overall technology base. Overall responsiveness to emerging threats and circumstances will have been enhanced. Second, if necessary, fielding the residual capability that remains at the completion of the demonstration could provide an interim and small-scale operational capability. Third, if the need is evident, the innovation developed can enter limited production as part of the prototype warfare concept.

Fighting Wars with Prototypes

In moving to limited production the focus shifts from assessing an innovation to fielding a capability that gives a relative military advantage. The capabilities are selected for production based on their ability to meet defined short-medium term needs; they are not simply blue-sky technology explorations.

In this, though, the capabilities will have some generic shortcomings. To meet the continual innovation objective, the new capabilities will be generally of limited complexity and therefore probably single role, not multi-purpose. The 4IR innovation process, in trying to sharply lower time to introduction to service and aid in-service supportability, reinforces the push towards simplicity. Moreover, affordability is a real constraint. There is not just a single capability being pulled forward from the experimentation program, but numerous. Funding needs to be spread across many prototypes. Overspending on one will adversely impact others and the overall force balance. In this it should be remembered that the prototype warfare concept envisages fielding many simple capabilities on a rolling basis, not a single exquisite one just once.

To help restrain costs the prototype warfare concept might produce tailored capabilities suitable mainly for particular roles or missions in specific geographic areas. Illustrating the idea, Rob Smith et al write that:

> "For example, vehicle needs are different for urban, desert, and mountain terrains. A single system is unlikely to excel across those three terrains without employing exotic and expensive materials and technology (becoming expensive and exquisite). The [tailored capabilities] could comprise the entire force or just do specific missions, such as Hobart's Funnies during the D-Day landings."[18]

The D-Day landing example raises the possibilities that a capability may be devised simply for a specific operation. The 4IR continual innovation process makes this practical at an affordable cost. Already the US and UK have experimented with sending unmanned air vehicle designs to 3D printers in remote locations or at sea, allowing tactical units to produce the air vehicles as circumstances require. This raises some intriguing possibilities for optimising a force deployed in the field on an almost daily basis. As Robert Kozloski writes: "consider the implications if a commander had the ability to select from a catalogue of weapon systems while planning for a mission and they were manufactured based on her specifications."[19]

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18 Rob Smith et al, 2018, '60. Mission Engineering and Prototype Warfare: Operationalizing Technology Faster to Stay Ahead of the Threat', *Mad Scientist Laboratory*, 11 June, http://madsciblog.tradoc.army.mil/60-mission-engineering-and-protot…are-operationalizing-technology-faster-to-stay-ahead-of-the-threat/ [Accessed 7 December 2018]. Hobart's Funnies refers to the 79th Armoured Division commanded by Major-General Sir Percy Hobart that developed equipment and tactics to perform specialised tasks in support of ground forces on and after D-Day. Hobart both improved on existing designs and created entirely new technologies. The armoured vehicles of the 79th became widely known as 'Hobart's Funnies'. See: IWM Staff, 2018, The 'Funny' Tanks of D-Day, https://www.iwm.org.uk/history/the-funny-tanks-of-d-day [Accessed 12 December 2018]

19 Robert Kozloski, 2017, 'The Path to Prototype Warfare", *War On The Rocks*, 17 July, https://warontherocks.com/2017/07/the-path-to-prototype-warfare/ [Accessed 7 December 2018]

Such a notion introduces several problems for adversary forces. First, the systems being defended against are designed to be single purpose not multi-role. They are optimised for the specific situation not to be a one-size-fits-all platform. In general an optimised system will perform better in the given situation for which it is designed. If the adversary uses multi-role systems they may be at a disadvantage from the start. Second, the systems being faced – being situational dependent - may not have been encountered before. Little may be known of them. Indeed with the 4IR continual innovation process, even if they have been faced earlier they could have been further customised and had any technical deficiencies or operational weakness removed. Third, with innovative systems it is possible they may use novel tactics. With limited time to respond, the adversary may be outthought and have no readily at hand satisfactory tactical response. Tactical responses then have to be broad in nature, which is inherently difficult to do. Lastly, the force being faced will be heterogeneous. A countermeasure against one system will most likely not work against another. Prototype warfare is inherently hard for an adversary to counter.

For the friendly force commander there is a further advantage in that the innovative capabilities in being inexpensively produced will be semi-expendable, maybe even disposable. They may not need to be carefully husbanded for the next fight and instead can be used in riskier situations than a large expensive platform can be. Moreover, losses of innovative equipment may be able to be readily made good if developed under the 4IR process.

These processes are also important for supportability. The digital thread connects all ecosystem participants across the equipment's life cycle. New variants can quickly incorporate availability and reliability improvements. The thread further ensures a well-tracked digital manufacturing database of maintenance items and replacement components is available to all, and that these can be readily ordered and dispatched, at times electronically, to a 3D printer.

Similarly, the equipment's digital twin can assist anyone anywhere in understanding how to support and maintain the equipment. Augmented reality could be used to show maintainers who have never seen the system how to rapidly diagnose and make repairs. Such a process might be similar to the digital shipyard example discussed in the previous chapter. A further gain is that such systems can also help train the equipment's operators in the field, possibly using tablets or other mobile devices.

There is, though, a dark side to 4IR prototype warfare. The significant gains it offers are not restricted to national military forces. In the 4IR there is an accelerated diffusion of ideas and technology globally. It is perhaps unsurprising that Islamic State has already demonstrated a form of prototype warfare in Iraq. Brian Castner observed that Islamic State:

> "did something that no terrorist group has ever done before... design their own munitions and mass-produce them using advanced manufacturing techniques. Iraq's oil fields provided the industrial base - tool-and-die sets, high-end saws, injection-molding machines - and skilled workers who knew how to quickly fashion intricate parts to spec. Raw materials came from cannibalizing steel pipe and melting down scrap. ISIS engineers forged new fuzes, new rockets and launchers, and new bomblets to be dropped by drones, all assembled using instruction plans drawn up by ISIS officials. ...[This] provides a disturbing glimpse of the future of warfare, where dark-web file sharing and 3-D printing mean that any group, anywhere, could start a home-grown arms industry of its own."[20]

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20 Brian Castner, 2017, 'Exclusive: Tracing ISIS' Weapons Supply Chain—Back To The US', *Wired*, 12 December, https://www.wired.com/story/terror-industrial-complex-isis-munitions-supply-chain/ [Accessed 7 December 2018]

Making 4IR Innovation Happen

> "there is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all those who profit from the old order, and only lukewarm defenders in all those who would profit from the new order.... Men intrinsically do not trust new things that they have not experienced themselves."
>
> Niccolo Machiavelli, *The Prince*, 1532

The concept of prototype warfare idea is made practical by the 4IR. The revolution's hyper-connectivity allows continual broad-based innovation. Such connectivity has a technical dimension as discussed across the previous chapters. However, there is also a social dimension about how individuals, military organisations, commercial companies, research institutions and academia all connect. This social dimension—like the technical—does not by happen by chance but is instead consciously created. For prototype warfare to be implemented, 4IR connectivity needs to be institutionalised in organisational structure, business practises and culture.

Catalysing Innovation: Enabling Prosumers

Innovation is by nature a risky venture with uncertain returns on the investment. It uses up resources that others might think would be better spent on more predictable outcomes. Accordingly, innovation to survive within businesses and bureaucracies customarily composed of competing fiefdoms needs a well-placed champion. Highly innovative organizations generally appoint an individual at the senior leadership level to maintain the overall strategic vision and to sponsor and promote innovation in line with that vision.

USAF usefully terms such people "Innovation Catalysts" as their aim is not so much to be innovative in themselves as to ignite innovation across the organisation. As Machiavelli noted, innovation is not popular. Innovation catalysts try to keep innovative ideas alive long enough to prove themselves or not. The latter is important: innovation catalysts must quickly kill programs leading nowhere; a fast fail can be a good outcome.

For defence forces to adopt prototype warfare they need a highly placed innovation catalyst as part of the senior leadership team, who is demonstrably able to make change happen and who can set the right tone from the very top. This innovation catalyst should be unambiguously in charge of guiding prototype warfare innovation through experimentation and into limited production, have the authority to set priorities, and have discretion over the use of a small innovation fund. The senior innovation catalyst is then responsible and accountable for making the vision of prototype warfare happen.

Undoubtedly the senior innovation catalyst's most important task is to foster and sustain an organisational culture of continual innovation. As Machiavelli's quote suggests, this is not easy. Cultures tend to lag behind change in the wider world as they are naturally built upon the past and what has previously worked. Historian Williamson Murray sagely observes that:

> "Rarely, if ever, do military organisations receive the opportunity to innovate with a clean slate. The past weighs in with a leaden hand of tradition that can often block innovation. And not without reason. The approaches that succeeded on earlier battlefields were often worked out at a considerable cost

> in blood. Consequently, military cultures tend to change slowly, particularly in peacetime." [21]

In the 4IR, though, the senior innovation catalyst's problem is even more complicated than the quote suggests. As in the past, such an individual needs to actively advocate for particular innovations that emerge. This traditional problem is eased somewhat by the experimentation program providing "new things" that people and the organisation overall can "experience themselves" and so understand their value - to again draw on Machiavelli. However, in the 4IR there is an additional, harder challenge.

The senior innovation catalyst must convince the organization that innovation as a concept is a necessary organizational attribute in the 4IR era. Continual innovation must be purposefully built into the organisation's DNA. This is not a task that can be undertaken by *diktat*, but rather requires a carefully reasoned and persuasive argument. Such an approach is not one that military commanders find intuitively appealing, preferring firm directions over debate. Crucially, however, a loud command to be innovative will not in itself lead to innovations. Developing an innovative culture is a hard slog that requires real intellectual effort.

Moving beyond the significant difficulties in embedding innovation within a military culture, a more inviting issue is determining the image the organisation holds of the future. This mental picture of how tomorrow's wars will play out is very important in guiding military innovation and making it tangible. Surprisingly often, peacetime innovation in military forces has proven effective in dealing with the challenges arising from changes in the character of war. In assessing

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21 Williamson Murray, 1996, 'Innovation: Past and Future', pp. 300-328 in Williamson Murray and Allan R. Millett (ed.), *Military Innovation in the Interwar Period*, Cambridge: Cambridge University Press, p.313.

numerous peacetime military innovations across 1920-1940, historians Barry Watts and Williamson Murray determined that:

> "The evidence points, first of all, to the importance of developing visions of the future. Military institutions not only need to make the initial intellectual investments to develop visions of future war, but they must continue to antagonize over such visions to discern how those wars might differ from pervious conflicts due to changes in military weaponry, national purposes, and the international security environment. As both the *Blitzkrieg* and interwar carrier aviation attest, any vision of future war is almost certain to be vague and incomplete rather than detailed and precise, much less predictive in any scientific sense. Nevertheless, without the intellectual effort and institutional commitment to evolve a vision of future war, military institutions will almost certainly fail to take the first halting steps toward peacetime innovation."[22]

Such visions of the future have been likened to impressionist paintings that give a broad sense of the uncertain future. They are not high definition images. Such paintings, though, need continual fine-tuning as circumstances change just as Claude Monet's haystacks were.

The senior innovation catalyst is well placed to develop the future war visions given the individual's centrality to making it real. In this, though, it's critical such future visions are agreed and articulated by the very top of organisations. This is because the vision of future war gives the organisation a whole new mental model to replace the now-considered obsolescent older ones. Replacing ideas people hold is a

22 Barry Watts and Williamson Murray, 1996, 'Military innovation in Peacetime', pp. 369-415 in *ibid*., p.406

complex challenge in itself, however a key part is having a new idea at hand.

Reframing the problem can be helpful. For example, reframing the threat posed by German submarines, the Royal Navy moved from trying to hunt them down and destroy them to focussing on ensuring as many cargo ships as possible safely arrived at British ports. Convoys then replaced hunter-killer groups. Counterinsurgency advocates will recognise that shift as they advise not destroying the enemy but protecting the people. Stephen Rosen calls this type of innovation changing the strategic measures of effectiveness.[23] Techniques useful in reframing include design thinking and assumption based planning.[24]

The reframing notion highlights that there are two kinds of innovations: sustaining, which enhances the capabilities of the current force, and disruptive, which creates a new, different force in the future.[25] Both are important. It's necessary to invest in near-term sustaining innovations while developing and experimenting with innovations that might create a wholly new way of war.

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23 Stephen Peter Rosen, 1991, *Winning the Next War: Innovation and the Modern Military*, Ithaca: Cornell University Press, pp. 109-182.

24 For design thinking see: Aaron P. Jackson, 'What is Design Thinking and how is it of use to the Australian Defence Force? Introduction to the Special Edition', *Australian Defence Force Journal*, Special Issue: Design Thinking: Applications for the Australian Defence Force, publication forthcoming in 2019. For the unusually named assumption based planning (as it actually deconstructs planning assumptions) see: James A. Dewar, 2002, *Assumption-Based Planning: A Tool for Reducing Avoidable Surprises*, Cambridge: Cambridge University Press.

25 Greg Satell postulates four kinds of innovation: sustaining, disruptive, breakthrough innovation and basic research. To avoid complicating matters and ease comprehension only sustaining and disruptive are used in this paper. However, Satell's classification approach is noteworthy. See: Greg Satell, The 4 Types of Innovation and the Problems They Solve, Harvard Business Review, 21 June 2017, https://hbr.org/2017/06/the-4-types-of-innovation-and-the-problems-they-solve [Accessed 11 January 2019].

The senior innovation catalyst has a crucial balancing role between the two innovation types. The concept of prototype warfare tends to favour sustaining innovations that enhance the force-in-being but disruption offers such a high payoff that it cannot be neglected.

In this its important to appreciate that innovations to be most successful need to integrate new technologies or thinking with matching employment doctrine, prudent organisational changes and, at times, adjusted professional military cultures. Historically, innovations introduced without considering these additional areas have delivered poor operational results.

The senior innovation catalyst needs to broadly guide the supporting changes necessary to ensure innovations actually deliver operational gains. This makes senior leadership agreement crucial as these changes will need to be made in areas of the organisation well-beyond the innovation catalyst's direct control.

The sting in the tail of all this is that resources in terms of both money and people are required to make the prototype warfare continual innovation approach work. Let's deal with the simpler issue of funding first.

A long-term, reliable budgetary allocation to innovation is needed. Large organisations always have money available but there are many competing priorities. In modern military forces much of the money is already committed to long-term support contracts with large multi-national companies and accordingly inaccessible. Furthermore, money for the future force is often held in large whole-of-defence major capital equipment budgets and thus also inaccessible. Moreover, in Australia there is now a large, liberally funded organisation created to advance defence innovation from a centralised perspective. The result is that individual service chiefs in the main have, at best, limited discretionary funds available to advance prototype warfare continual innovation concepts.

The difficulty is that the individual Services may be the best placed to make prototype warfare real. The concept looks mainly to the near-medium term with experimentation as a crucial foundation. The 4IR prosumer notion places emphasis on the end-user being deeply involved in defining the need, designing the product and influencing production. The individual Services have the prosumers, not necessarily the more remote head-office organizations.

An answer to the dilemma in rather general terms might be to use the central organisation to fund long term innovation while the Services focus on the short-medium term prototype warfare aspects. The balance between the central organisation and the individual Service innovation activities is another area for the senior innovation catalyst to be responsible. Such a solution explicitly implies that each Service provides a small budget for prototype warfare innovation.

To suggest a quantum, a budget of about $20-$30m might be appropriate. This is somewhat frugal. In way of contrast, some defence forces spend 2-4% of their overall budget allocation on innovation; private companies sometimes 6% or more. The budget proposed is principally for the experimentation phase of the prototype warfare concept. The pull-through into limited production may be better funded from capital equipment funding sources. That would be a complex, bureaucratic and political drama in itself and best left to the individual Service's senior innovation catalyst to manoeuvre depending on the circumstances of the time.

Moving now to the more problematic issue: freeing up skilled people from other priorities. The senior innovation catalysts can obviously not do it all by themselves. Moreover, studies indicate that: "the best way to foster innovation in a large bureaucracy is to create enclaves that can operate as small organizations."[26] Paradoxically, innovation catalysts need to work to create a task-focussed bureaucracy: a purposeful group that creates and nurtures innovation over the long haul.

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26 Captain Terry Pierce (Rtd), 2018, The Navy Needs a New Engine of Innovation, *U.S. Naval Institute Proceedings*, Vol.144, No.11, November, pp 389-391.

Subordinate innovation catalysts would need to be placed across the lower-levels of the organisation to best advance the prototype warfare continual innovation concept. This may not necessarily reflect the extant hierarchical framework. Scattering the subordinate innovation catalysts in some fractal pattern may better induce the innovation sought in a version of the 'butterfly effect'. Irrespective of where located, all the subordinate innovation catalysts would be engaged helping evolve the strategic vision of future war and its related experimentation campaigns. They would make tangible a network of enduring innovation.

In considering implementing such a plan, USAF recently found an issue that may affect others. With the out-sourcing of expertise, USAF has "lost the capability to assess the technical baseline of…programs."[27] An innovation network would need to include such a capability to avoid wasting its scarce funding on less feasible proposals.

There is a further key personnel issue to consider. Stephen Rosen concluded from his case studies of peacetime innovation that:

> "Rather than money, talented military personnel, time, and information have been the key resources for innovation. The study of peacetime military innovation showed that when military leaders could attract talented young officers with great potential for promotion to a new way of war, and then were able to protect and promote them, they were able to produce new, useable military capabilities. Failure to redirect

27 National Academies of Sciences, Engineering, and Medicine, 2018, *Creating Capability for Future Air Force Innovation: Proceedings of a Workshop—in Brief*, Washington, DC: The National Academies Press. https://doi.org/10.17226/25220 [Accessed 27 November 2018].

> human resources resulted in the abortion of several promising innovations."[28]

Military personnel have ambitions. If the innovation network becomes perceived as a career impediment, people will avoid it, especially as it inherently is an area that others find disruptive and threatening. The innovation network's key asset – thinking people – would need some protection from the organisational 'antibodies' that fight change. Giving people a stable environment that supports them makes innovation more likely to succeed.

Partners With All: Ecosystem Issues

Implementing the 4IR model for continual innovation means building a collaborative ecosystem. This is more than simply leveraging off the defence-industry-academia linkages that major capability equipment projects like Wedgetail or JORN build. The enduring linkages in these examples progressively developed around a central core of a well-funded, long-life, well-defined acquisition project. The prototype warfare concept is somewhat different in needing a well-integrated, collaborative ecosystem that itself continuously evolves as frugally-funded, short-life, ill-defined hardware and software comes and goes.

As with innovation overall, such an ecosystem does not just happen. It will require being purposefully created, although the larger national innovation efforts underway in both the civilian and joint defence space provide a good starting base. In that regard, the very idea of prototype warfare with its continual innovation to meet short-medium term needs and the prospect of possible limited production

28 Stephen Rosen, *op.cit*, pp 252-253.

will in itself influence and shape the ecosystem and wider market environment.

The prototype warfare concept places a premium on speed relative to strategic competitors. Time to in-service is crucial to gaining an advantage. Creating such market conditions will act to favour and bring forward dynamic, self-motivated companies. In the experimentation space in particular, the more agile and entrepreneurial local Small-Medium Enterprises (SMEs) might be better placed than some Australian branches of large global multinationals.

Traditionally, SMEs rely on the larger companies to take their ideas into production and then later provide logistic support. The 4IR model turns this on its head. The SMEs could – at least theoretically – take up additive manufacturing for limited production runs and in being part of the ecosystem have an established pathway for long-term support.

A contemporary example of a very small SME illustrates what is practical under the 4IR framework. An Australian maxillofacial surgeon became a prosumer by designing individually-tailored medical implants able to be made on 3D printers. After an experimentation phase to prove the concept, the surgeon then formed the OMX Solutions company which, with six biomedical and IT staff, undertook limited production. OMX has so far made 120 unique implants.[29]

Such possibilities indicate the 4IR could lower the traditionally high barriers to entry to the defence market allowing new participants of any size. The composition and the structure of the defence industry base might shift. No longer would it necessarily be that specialist large defence companies always have a distinct advantage. SMEs and non-defence commercial companies could enter the defence marketplace through offering innovative proposals with fast production cycles.

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29 Sarah-Jane Fraser, 2018, '3D jaws take a bite at disruption', *The Weekend Australian*, 8-9 December, p.29.

Enabling SMEs and more non-defence commercial companies to be involved in developing and producing defence equipment, albeit on a small scale, could bring some real strategic advantages. SMEs and commercial companies can potentially bring new mobilisation options and possibilities. Multiple dispersed small-scale production sites could complement the traditional large single-site dedicated defence industry factory option.

Tantalising while such possibilities may be, the key to 4IR is the interaction between the prosumer and the ecosystem. The ecosystem requires access to the consumer, as they must be deeply involved in the innovation's design, refinement and validation process. In the prototype warfare continual innovation model this suggests pushing such access down at times to the unit level.

There are implications in this. It's always tempting to outsource such interfaces between the military and the outside world to large consulting firms. However, in the prototype warfare case continual innovation is sought, rather than once-only, making a short duration consultancy interface of less value. Ideally the knowledge of continual innovation in being part of the core business of the 4IR military should be retained in-house. The military themselves need to deepen and broaden their relationships with industry, research sites and academia to take full operational advantage of the quickening pace of technological change.

Keeping the prosumer at arms length from the ecosystem will noticeably dilute the significant benefits the 4IR model brings. With funds scarce, this would be an unnecessary own goal. In the 4IR the military needs to talk to the ecosystem directly.

The military in particular needs to talk about what it needs. The innovation catalyst network would need to work with units and other lower level organisations on what they require to translate the agreed strategic vision of future war into reality. The large centralized organisation can address the big matters related to the future joint force but the Service innovation catalyst networks need to focus on the short-medium term smaller-scale issues. At this level the aim is to find, design, test and refine affordable innovations that can give an out-sized return under small-scale production.

The prosumer concept further suggests that units could potentially form their own functional relationships with SMEs, larger companies, research institutes and academia. It might be a case of the innovation catalyst network being 'matchmakers', providing seed funding and then stepping back to let the unit-business-academia relationships develop and prove innovative prototype warfare ideas. Each unit then potentially transforms into an operational laboratory that develops and verifies innovations.

There is a further step possible: units could be encouraged to solve their own problems. Before the age of lean organisations, military bases had some spare capacity to be able to devise simple innovations themselves. Empowering local bases again by providing suitable facilities and technology such as low-cost commercial 3D printers might once more encourage bottom-up innovation. As much, it would institutionalise the idea of innovation through educating military personnel at all ranks and levels about the possibilities 4IR and its associated technologies offer.

If that sounds somewhat implausible, the Australian Army has recently acquired several hundred hobbyist drones so all in Army have the means to educate themselves about such technology and the operational gains drones can bring. If it can be done for drones, it might be practical for the 4IR as well.

The 4IR with its notions of prosumer and supporting ecosystem promises much. However, for the military the focus needs to remain on using the 4IR to make prototype warfare real. This is a demand that can provide the discipline and structure necessary to the many alluring possibilities.

4IR Prototype Warfare Program Parameters

The discussion so far about constructing a 4IR prototype warfare program may seem rather abstract for some. The type of innovations that the program might support could appear somewhat vague. Of course, precise definition awaits the development of the innovation catalyst network and the vision of future war discussed earlier. However, some broad parameters are discernable.

Focus and/or Diversify? A key decision concerning a 4IR prototype warfare program is whether to focus investment on particular areas or to invest widely in a more diversified portfolio. This is a balance of investment question: what percentage of the funding goes into probable gains versus supporting 'blue sky' innovations that might be really important? The US Third Offset strategy focuses on five key areas but even so Secretary Carter noted that the intent was to also seed many different investments to "see what germinates," rather than determining from the start what is expected to work and liberally funding only those.[30]

This is more complicated than deciding which technologies or mission areas are favoured. This also involves judgments about the expected future strategic environment. If there is a high level of uncertainty about the future, diversification makes sense. On the

30 The five areas are autonomous learning, human-machine collaborative decision-making, assisted human operations, advanced manned-unmanned systems operations, and network-enabled autonomous weapons and high-speed projectiles.

other hand, if the future is certain, focussing on innovations for that anticipated environment is preferred. In thinking about the issue foresight techniques may help. Capabilities that will be useful across multiple alternative futures may be the best ones to fund. The catch is that this may divert monies away from building up capabilities that are crucial in the few really stressful possible tomorrows.

In this regard, the earlier discussion in Chapter Two is worth noting. If the Toffler's argument that "the way we make war reflects the way we make wealth" was accepted, then hybrid wars seem the most likely type of wars in the 4IR era. A recent study indirectly supports this in determining that irregular wars are common across four different alternative futures.[31]

Have a Real Problem Set. Moving down from balance of investment considerations, the ecosystem participants will be better able to propose innovations if they have a defined problem set. What is the problem the military wishes them to solve? Within this of course is that the military is not always sure what industry can offer and so can unhelpfully modify the operational problem posed.

This issue is more important to the overall success, of prototype warfare in particular and continual innovation in general, than it may at first sight appear. A recent study compared innovation in the US against Australia and determined that a lack of a clear problem set noticeably hindered Australian innovation efforts. Don Scott-Kemmis discerned that a significant characteristic of successful US innovation was:

> "A strong focus on innovation objectives at the program level, often based on defined 'missions' and public private partnerships to develop advanced technologies and address

31 Peter Layton, 2018, *Tomorrow's Wars Insights From Our Four Alternative Futures*, Canberra: Air Power Development Centre.

> bottlenecks that limit industry-wide performance — this approach provides a continuous negotiation between top-down and bottom-up innovation priorities in a context of strong accountability."[32]

A way for military forces to approach this problem may be to adopt Robert Gold's mission engineering concept.[33] This advocates treating the end-to-end mission as the system to optimize, with the individual systems simply components. This approach does not predetermine the nature or type of innovation; it could be doctrinal as much as technological. Mission engineering is seen to assist in framing the correct problem, put forward an accepted end state for mission success, align all ecosystem participants and provide an assessment framework to judge success. Of interest to air forces, two areas currently perceived as needing mission engineering innovation are air superiority in contested environments and wide area surveillance and targeting.

In this it's important to recall that 4IR prototype warfare aims to address short-medium term problems leaving long-term needs to the joint service major capital equipment program to solve.

Time to Service is Critical. The 4IR prototype warfare program is based on the notion that continual innovation will deter adversaries or, if needs be, defeat them in combat. The time an innovation will take to enter service is key. Importantly, this time is relative to others, not the gaining military force. Funding an innovation that arrives too late to influence potential adversaries is a waste of scarce resources.

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32 Don Scott-Kemmis, 2018, *Myths, Crises And Complacency: Innovation Policy In The United States And Australia*, Sydney: United States Studies Centre, p. 25.

33 Robert Gold, 2016, *Mission Engineering*, 19th Annual NDIA Systems Engineering Conference Springfield, VA, October 26.

Curiously perhaps, this is an area where historically military forces have problems.[34] In peacetime, military forces have often kept abreast of broad changes in the envisaged character of future war and innovated accordingly. Such innovations, though, are often made without considering specific potential adversary capabilities, only the general character of war changes. In the interwar period the US Navy got the carrier warfare change in the character of war right but overlooked Japan's Zero fighter. This proved a costly error, albeit not ultimately terminal. In the 4IR prototype warfare program, getting the timing right will require a much better appreciation of the emerging real-world capabilities of possible adversaries. Suggested innovations should be judged relative to others not ourselves.

Implicit in this debate is whether to invest now or later. Some innovations may do with further refinement before funding for development and there may be time to wait for this to be undertaken. This cuts back to the issue of focussing or diversifying. The part of the 4IR prototype warfare program being applied broadly to field systems across a wide mission set may throw up good ideas that are not really needed in the envisaged short-medium term. Funding may be delayed until there is a higher likelihood of being necessary.

Risk and Risk Assessment. Decisions on moving forward into limited production will also hinge on assessments made of the risks involved. The technical risks involved are arguably relatively straightforward to determine. An oft-used approach is to employ NASA's Technical Risk Level (TRL) definitions. Using this, an experimentation program would aim to build a prototype to TRL 6 while to enter limited production the prototype would need to be further developed to TRL 7. There are, though, risks beyond technical ones.

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34 Stephen Rosen, *op.cit.*, pp 57-105.

Not all innovations can be pulled forward into service; there will inevitably be insufficient resources for that. Some, perhaps most, won't make the cut and will be abandoned at the end of the experimentation phase. Such decisions will be based around deliberate assessments of the risks of not proceeding. For the military the consequences of a poor risk assessment may be serious so simply saying 'we'll accept the risk' does not suffice. Instead, in rejecting useful innovations, steps may need to be taken that will limit the damage if the feared risk eventuates. The intent should be to lower the costs incurred to an acceptable level if the risk occurs. While innovation is not free, the decision to not innovate is one that can also impose costs.

Plug and Play. With the innovations aiming to address short-medium term needs, they should be compatible with, and fit readily into, the existing force structure. Systems that cannot connect with the extant force are more likely to be a weakness than an asset regardless of how innovative they are. Ideally innovations will be 'plug and play' and be designed and built to easily integrate with the overall ADF systems of systems. While this suggests and includes technology compatibility, non-technological innovations may also need to fit easily into the current force. An innovation at odds with current agreed joint service doctrine and difficult to train current personnel on may be problematic to introduce.

Sustaining or Disruptive. The main thrust of the 4IR prototype warfare program is to improve the current force not undermine it. Disruptive innovations impacting the wider joint force structure might best be undertaken through the joint service major capital equipment program. Even so, there may be some disruptive innovations in limited Service-specific areas that are too effective to ignore. In examining innovation proposals, a balance may have to be struck in the quantum of funding allocated between sustaining and disruptive innovations.

Affordability. The 4IR prototype warfare program is meant to be a low-cost innovation approach. The innovations need to be low cost to experiment with to prove or disprove their utility. The stress on affordability means that innovations are likely to be single role capable only and offer a tailored capability within that. This suggests the innovations will generally bring incremental gains only, not some revolutionary improvement. In this, it should be borne in mind that the 4IR means one-off complex items can be potentially produced quite cheaply so the affordability issue may not necessarily mean low complexity – even if it implies it.

Limited Production Possibility. The whole reason for the experimentation program is to prove or disprove an innovation is suitable for limited production. The innovation proposed needs to be able to move ahead to that step.

4IR Built. The innovation should be designed and produced under the 4IR framework. Given this, the full prosumer and ecosystem gains will be able to be realised. This will further ensure that the military force will strengthen their relationship with industrial, research and, academic networks so as to be able to best exploit 'quick turns' in technological change.

Short Life–Cycle Capabilities. The innovations are only expected to have a short-life, maybe only as long as single tactical event. The 4IR continual innovation model means that innovations can undergo a continuing process of refinement. Today's innovation might be replaced tomorrow by an even better one. A high turnover of innovations further means that 'plug and play' becomes even more important from a technical and human operator perspective.

This all implies the phased introduction of an innovation, where items are acquired in stages with each group incorporating improvements gained from the earlier deployments. This continual innovation through learning is a key element of both the 4IR and the prototype warfare concept.

USAF's Project Maven provides a thought-provoking example of continuing innovation occurring in the field and how such a capability may be built into 4IR advanced technology. The project aims to use artificial intelligence (AI) to rapidly assess the vast amounts of imagery USAF unmanned air vehicles collect.

> "While Project Maven is still in 'very, very early' stages, it has already been deployed to five or six combat locations including the United States Africa Command. There, the team is testing its "prototype warfare" strategy — deploying a capacity that is around '80 percent' and getting comfortable with the idea of making improvements 'on the fly.' There's a button right in the Project Maven user interface…that says 'train AI.' This allows for the retraining and improvement of the algorithm based on new data, and it's a key capacity. After deploying Project Maven to AFRICOM in December…the team updated the algorithm about six times in five days."[35]

Augmentation not Replacement. In considering the list of attributes above, it is readily apparent that the 4IR prototype warfare program aims to field carefully tailored innovations that augment not replace the current force structure. Prototyping warfare is more about quickening the enhancement of existing capabilities rather than replacing them with emerging technologies.

35 Tajha Chappellet-Lanier, 2018, 'Pentagon's Project Maven responds to criticism: 'There will be those who will partner with us'.', *fedscoop*, 1 May, https://www.fedscoop.com/project-maven-artificial-intelligence-google/ [Accessed 11 December 2018]

Air Environment Matters

The parameters discussed give an outline of the various factors to consider in thinking about 4IR prototype warfare innovations and are broadly applicable to all military forces. It may be useful in further illustrating and examining the 4IR prototype warfare concept to delve deeper and be more context specific. This examination discusses the air environment to bring out additional ideas. In this it must be noted that the 4IR prototype warfare concept of continual innovation has some difficulties when applied to current manned aircraft. These aircraft were designed in a third industrial revolution world and consequently making hardware or software changes is technically challenging, costly and time consuming. This is especially so with stealth aircraft that effectively have unalterable mould lines and very complicated, interwoven software.

Given this constraint, there are broad areas where the 4IR prototype warfare continual innovation concept might be appropriate.[36] There are two ways to group innovations: in terms of technology or related to operational needs.

Recent publications examined fifth generation air warfare and then extended this into algorithmic warfare.[37] Fifth generation air warfare comprises four parts: a network, a combat cloud operational concept,

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36 The longer-term joint force innovation is being undertaken in Australia by the Next Generation Technologies Fund that is focussed on nine priority areas: Integrated intelligence, surveillance and reconnaissance; space capabilities; enhanced human performance; medical countermeasure products; multidisciplinary material sciences; quantum technologies; trusted autonomous systems; cyber; and advanced sensors, hypersonics and directed energy capabilities. Innovations in many of these areas would be clearly well beyond the limitations and constraints of the envisaged 4IR prototype warfare program.

37 Peter Layton, 2017, *Working Paper 43: Fifth Generation Air Warfare*, Canberra: Air Power Development Centre. Peter Layton, 2018, *Algorithmic Warfare: Applying Artificial Intelligence to Warfighting*, Canberra: Air Power Development Centre.

a multi-domain focus and a fusion warfare construct. Algorithmic warfare refers to 'algorithms', which in computing are the sequence of instructions and rules that machines use to solve problems. Algorithms are the crucial conceptual and technical foundation stone of modern information technologies, emerging intelligent machines and 4IR. Algorithmic warfare concepts combine intelligent machines, big data and cloud computing.

Combining the two new warfare approaches indicates that the key technologies useful across multiple mission sets include the combat cloud, human-machine teaming, artificial intelligence and robotics.

In considering operational needs, there are several areas worth considering under the 4IR prototype warfare continual innovation concept.

Off-Board Mission Systems. Air forces are progressively becoming network enabled with force elements receiving data and information from off-platform sources. Manned aircraft may be difficult to modify, but they can readily receive information generated by off-board systems and sensors. New and novel off-board systems and sensors could be developed that would provide enhanced situational awareness to manned aircraft, or alternatively perform off-board functions for the manned aircraft on command. The sensors and systems could be ground or sea based, or fitted to unmanned aircraft. This is in line with the 4IR notion of hyper-connectivity with links to hundreds - perhaps thousands - of small, widely dispersed low cost IoT sensors.

Uninhabited Aerial Vehicles (UAV). UAVs are the air vehicle part of unmanned air systems. The top-end UAVs are complex air vehicles more akin in technology to third industrial age manned aircraft than the 4IR. However, much smaller-scale simple vehicles offer transformational 4IR potential, especially when used 'en masse' in a swarm. Being uninhabited, many of the costly manned aircraft qualification and certification processes are unnecessary. UAV innovations could be low cost although they would need to be 'plug and play' within the existing and emerging command and control networks.

Airbase Defence. Airbases with their parked aircraft and complex support facilities have always been attractive targets for hostile forces in all kinds of conflicts. In a period of hybrid wars the possible threats to air bases are noticeably broadening and now range from hobbyist drones up to Intermediate Range Ballistic Missiles. It is an area calling out for innovative thinking.

Aircraft Turnaround. The time an aircraft spends on the ground is time wasted, as commercial airlines are well aware. As the Israelis demonstrated in the Six Day War, quick combat aircraft rearming and turn round times can be a very significant force multiplier. New concepts and technology that greatly improves sortie generation rates whether for fast jets, maritime patrol or transport aircraft could prove very important, especially for small air forces.

Operations Other Than War. While not a technology in itself, the area of non-warlike operations remains a fertile area for original concepts, building prototypes and experimentation. Humanitarian, peacekeeping, disaster relief, and constabulary missions could all potentially make good use of 4IR prototype warfare continual innovation.

Conclusion

The interweaving of the second and third industrial revolutions is creating the fourth industrial revolution. Such integration allows a continuous and cyclical flow of information and actions between the physical and digital worlds. Many organizations already have some physical-to-digital and digital-to-digital processes but it's closing the loop from digital back to physical and then acting upon analysed data and information that marks the big technical advance. This change moves the customer to the centre of the production process.

Customers will be able to adjust order specifications not just before ordering but also during design, manufacturing, assembly and testing. Warfighters can be deeply involved in customising their equipment to be optimal for their needs and operating environment. Moreover, warfighters can also now make reliability improvements and plan on-time logistic support.

The fourth industrial revolution creates the possibility of a future defence force structure that rapidly evolves to meet emerging operational demands. The time lag between new challenges arising and technological responses to those challenges will drop dramatically. Continual innovation will be the dominant quality of the future force.

Such production advances make use of the digital thread and the digital twin. The digital thread runs from start to finish, connecting the entire design and production process with a seamless strand of data that stretches from the initial design concept to the finished product. Changes to the design are then instantly transmitted across the whole process.

The digital twin is a model of the product that gives insights into the inner workings and operation of the product, simulates possible scenarios, and aids understanding the impact of changes. This twin runs across the value chain from product inception to service allowing later operating experiences and data to be fed back into the digital model to update it and prompt possible production changes.

These advances, when combined with advanced manufacturing techniques like 3D additive printing, significantly change traditional notions of military equipment production. Manufacturing times can be halved or more; surge production in time of crisis is once again a realistic possibility. Moreover, specialised tooling is no longer essential, allowing commercial production lines to be quickly switched to military purposes simply by connecting to the ecosystem. Manufacturing may now occur anywhere.

Production lines can be widely dispersed within the nation or around the globe to be either near the user, transportation hubs or for protection in case of attack. The crucial element now is not having adequate skilled labour to build military equipment but instead the investment capital to set up connected digital factories employing robotics, advanced manufacturing techniques and artificial intelligence.

Such improvements rely on a deeply interconnected ecosystem, a heterogeneous network that very closely collaborates. This digital network can include national and transnational individuals, companies, industries, communities and governments together with machines, robots and Internet-of-Things devices. In a way, all become part of the national defence organisation in driving innovation and production. The fourth industrial revolution moves considerably beyond the factory door.

All this allows large-scale adoption of the prototype warfare concept. Under the fourth industrial revolution, prototypes—after being proven in experimentation programs—can now be produced affordably in limited numbers and then quickly introduced into service. It will be practical to rapidly field a variety of low-cost, less complex systems and then replace these with improved variants or something totally new on a regular basis. However, as the 'prototype warfare' phrase emphasizes these limited production items are rather immature and less than fully developed.

The short-life, semi-experimental items produced using fourth industrial revolution processes would form a small part of an overall national defence force structure, augmenting the long-life, more complicated, well-proven platforms. The prototype warfare concept would address short and medium term needs with the existing major equipment acquisition system remaining focused on the longer-term needs and associated major platform buys.

In this the prototype warfare concept capabilities will have some generic shortcomings. They will probably be single role not multi-purpose, be designed with a stress on ease of manufacture and in-service supportability, and have sharp affordability boundaries. Accordingly, the concept inherently favours sustaining innovations that enhance the force-in-being rather than disruptive innovations, which create a new, different future force.

The prototype warfare concept relies on exploiting the fourth industrial revolution's ability for continuous innovation but more than technology is necessary. For defence forces to adopt prototype warfare they need a highly placed 'Innovation Catalyst' within the senior leadership team, who is demonstrably able to make change happen and who can set the right tone from the very top. This innovation catalyst would guide prototype warfare innovation through experimentation and into limited production, have the authority to set priorities and have discretion over the use of a small innovation fund ($20-$30m).

Undoubtedly the innovation catalyst's biggest challenge is to embed the notion of continual innovation into the organisation's DNA. To become a 4IR military force requires encouraging and enabling ongoing innovation across the organisation. Innovation cannot be commanded but must instead become part of the organisation's culture and be rewarded. Of course, an innovation catalyst cannot do all this alone. A 'messiah' is not enough; disciples are also necessary.

Subordinate innovation catalysts should be placed across the lower-levels of the organisation to advance the prototype warfare continual innovation concept. This may not reflect the extant hierarchical framework. Instead, scattering the subordinate innovation catalysts in some fractal pattern may better induce the innovation sought in a version of the 'butterfly effect'. They would make tangible a network of enduring innovation.

Implementing the fourth industrial revolution model for continual innovation means building a highly collaborative defence-industry-academia ecosystem but there are implications. The ecosystem requires access to the military consumer, as they must be deeply involved in the innovation's design, refinement and validation process. This means that the military cannot outsource interfacing with the outside world. Continual innovation in being part of the new core business of the fourth industrial revolution military should be retained in-house to ensure full operational advantage is taken of the quickening pace of technological change.

Moreover, the prototype warfare's continual innovation with the prospect of possible limited production will reshape the defence marketplace. There will now be a premium placed on speed of technological development relative to strategic competitors. Time to in-service is crucial to gaining an operational advantage and this characteristic favours more dynamic companies.

Agile, local Small-Medium Enterprises (SMEs) might be better placed than large, distant global multinationals. Traditionally, SMEs rely on the larger companies to take their ideas into production and then later provide logistic support. The fourth industrial revolution overturns this. The SMEs could embrace additive manufacturing for limited production runs and in being part of the ecosystem have an established pathway for long-term support.

Such possibilities indicate the fourth industrial revolution could lower the traditionally high barriers of entry to the defence market allowing new entrants of any size or type. The composition and the structure of the defence industry base might shift. No longer would specialist large defence companies always have a distinct advantage. SMEs and non-defence commercial companies could enter the defence marketplace through offering innovative proposals with fast production cycles.

The fourth industrial revolution bids fair to overturn many of our long-held conceptions of defence equipment manufacturing and long-term support, confirming the Toffler's "the way we make war reflects the way we make wealth" premise. A hyper-connected defence-industry-academia ecosystem can ensure continual innovation, bringing in its wake prototype warfare and the ability to have a rapidly evolving force structure. While only 10-15% of a force structure might be composed of prototype warfare equipment and concepts, this may be sufficient to decisively win on the battlefield. The combination of the fourth industrial revolution and prototype warfare might create the silver bullet needed in the complex, volatile, chaotic military environment of 21st Century.

Prototype Warfare, Innovation and the Fourth Industrial Age

Australian companies, researchers and academics are being pushed by the Australian Government to embrace the fourth industrial revolution. The effect of this push will change the way of preparing for and waging war, as the definition and characteristics of warfare will be changed by the adoption of new technologies, such as robotics, artificial intelligence, augmented and virtual reality systems, and additive manufacturing.

This monograph outlines the fourth industrial revolution and discusses how best to leverage off these continually changing innovations through experimentation, prototyping and a hyper-connected defence-industry-academia ecosystem.

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