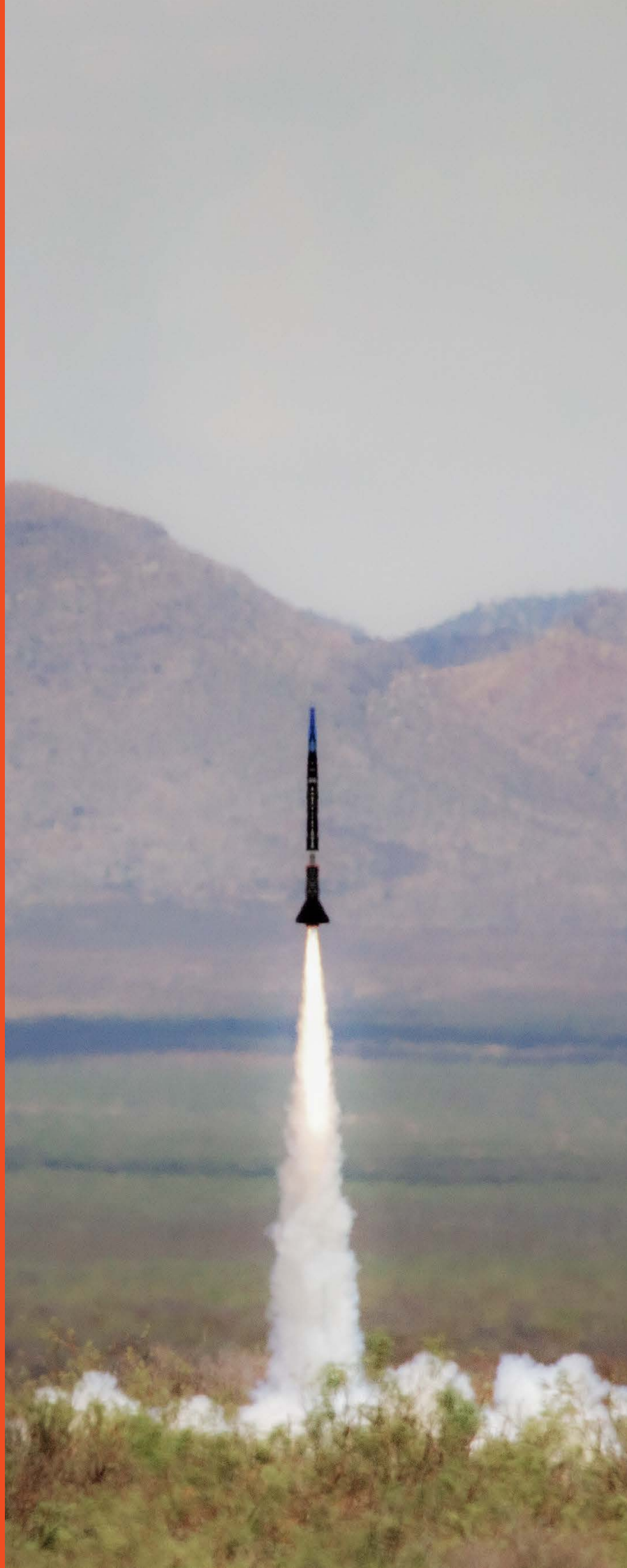
THE UNIVERSITY OF SYDNEY

Australia's GWEO Enterprise

A Workforce Capacity Estimation Study

March 2024



We recognise and pay respect to the Elders and communities – past, present and emerging – of the lands that the University of Sydney's campuses stand on. For thousands of years they have shared and exchanged knowledges across innumerable generations for the benefit of all.

Australia's GWEO Enterprise

A Workforce Capacity Estimation Study

Brendan Waters [a]
Juan Rasines Mazo [a]
Matthew Cleary [a,b]

[a] School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, NSW 2006, Australia

[b] Digital Sciences Initiative, The University of Sydney, NSW 2006, Australia

School of Aerospace, Mechanical and Mechatronic Engineering,
Digital Sciences Initiative,
The University of Sydney,
NSW 2006, Australia

March 2024

How to cite this report
A Workforce Capacity Estimation Study,
Waters, B. et al.
"Australia's GWEO Enterprise: A Workforce Capacity Estimation Study,"
Digital Sciences Initiative, The University of Sydney, 2024

Correspondence
For further details on *A Workforce Capacity Estimation* Study, please contact Professor Matthew Cleary
by emailing m.cleary@sydney.edu.au

Some of the images provided are courtesy of Department of Defence

Graphic design
Roman Balla

March 5, 2024

Executive Summary

Significant effort will be required to secure both the capability (technology) and capacity (workforce) needed for the fulfilment of the Guided Weapons and Explosive Ordnance (GWEO) Enterprise's mission to establish a successful Australian industrial base for the design, manufacture, maintenance, upgrade and disposal of long range fires and other guided weapons systems.

This report focuses on capacity; developing an evidence-based methodology for estimating the size and composition of the future workforce with clearly labelled assumptions. It makes a preliminary estimate of that workforce using data in the public realm, and contextualises that estimate relative to the current supply of suitably qualified people. Three baseline scenarios are postulated as to what Australia's GWEO capability might look like. The third of these - a resilient industry with substantial local manufacturing, but with continued dependence on the global supply chain for base components - represents a long term proposition for a mature industry. This report performs analysis of that scenario.

A three-tiered structure is defined for each essential element of a resilient domestic industry; that is, there are three tiers for capability, three tiers for supply chain and three tiers for capacity. The estimation methodology proposes a top-down calculation through the supply chain. Firstly, the Tier 1 workforce employed by industry Primes is estimated through a productivity metric (**`Revenue-per-Employee`**), an assumed capability portfolio of guided weapons systems to be manufactured in Australia, and scaling by the value of Australian acquisitions.

For purposes of demonstration and making a preliminary estimate, a hypothetical guided weapon capability portfolio has been selected using a range of public sources, and the value of acquisitions has been estimated from the trend in announced ADF acquisitions over the past two decades. The preliminary Tier 1 Prime workforce estimate is 6,691 people. Secondly, the combined Tiers 2 & 3 workforce employed by sub-system and base component/material suppliers, respectively, are estimated for each Prime, using public data for number of suppliers-per-prime, statistical data on company sizes and fraction of employees in technical roles, and the fraction of the Tiers 2 & 3 companies which are postulated to be required located in Australia due to the criticality of their input. The preliminary Tiers 2 & 3 workforce estimate is 1,385 people assuming just 6.1% located in Australia. Therefore, the preliminary estimate for the Australian GWEO workforce working in technical roles is 8,076.

The breakdown of this workforce, albeit using only a single publicly available reference point from a European context, is 2,180 people in specialised roles (PhD or research MPhil qualified), 2,746 in professional roles (Bachelor or advanced trade qualified), and 3,150 in vocational roles (trade qualified). These numbers for specialised and professional roles are contextualised through comparison to Australian domestic graduations. Assuming that 50% of specialised graduates were to go into the guided weapons industry it would take 15 years to build the workforce at current rates of supply. Similarly, assuming 10% of professional graduates were to go into the industry it would take 7 years to build the workforce. Given that Australia has lost strategic warning time for conflict in our region, these lead times to establish an appropriate guided weapons manufacturing capacity would appear to be too long and are a call to arms. A coordinated approach to training and education is necessary. It will need to involve universities and vocational training institutions, industry, government, defence and peak bodies including the Australian Space Agency and Engineers Australia.

The key strengths of this work are that it has been conducted independently by the University of Sydney using publicly available data and disseminated by a publicly available report. The methodology is sound and defensible. However, the public-realm data that feeds into that methodology to make the preliminary estimates is sparse leading to wide uncertainty. A series of industry survey questions have been created which can be used to obtain a wider range of data points for future estimations with lower uncertainty.

Preface

In June 2022, the University of Sydney Rocketry Team (URT) beat over 100 entrants to win Spaceport America Cup, which is the largest and most prestigious international sounding rocket competition for university students, with their 30,000 foot rocket called Bluewren.

In the months that followed this success, there were a series of visits to the University of Sydney by defence industry managers wishing to tap into this talent pool that comprises up to 100 students studying for a range of degrees including aerospace, mechanical, mechatronic and electrical engineering, computer science, various science disciplines, and business/accounting. As the Academic Supervisor of URT, it became clear to me that the GWEO Enterprise which began in 2021 was starting to create a pull factor on future workforce needs.

It was also clear that if the nation was to succeed in establishing a domestic guided weapons manufacturing sector, it would need a technical workforce across a wide range of qualification levels (trade qualifications through to PhD) and a wide range of specialisations. A coordinated approach would also be needed given the aggressive timelines stipulated by GWEO and the strong competition from other industry sectors including energy, housing, construction and, very soon, the nuclear submarine program.

To this end, academics at the University of Sydney teamed up with colleagues at the University of Queensland, Royal Melbourne Institute of Technology (RMIT) and Monash University to scope the needs and gauge appetite for a broad education and research collaboration amongst academia, industry and government, bringing in both the defence and space sectors. Two workshops were held at the University of Sydney in April and September 2023 involving representatives from over 25 companies, peak bodies and government departments. Training theme areas and programs were discussed and a very clear mandate to push this collaboration forward was established. A missing element was identified in that there is, until now, no independent and publicly available report on the size of the workforce that will be needed to support GWEO. Therefore, with funding from the University of Sydney Digital Sciences Initiative, the present report was commissioned to fill that gap. It is intended as a work in progress.

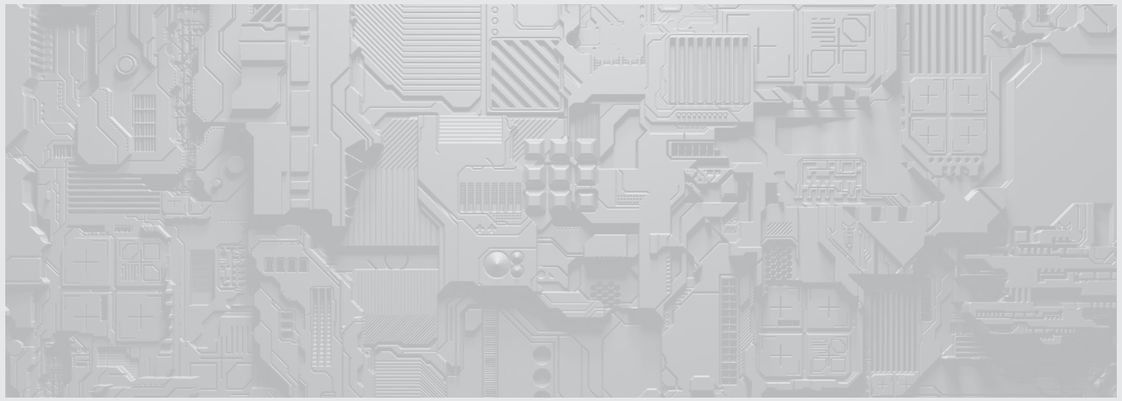
A defensible methodology has been developed within, and a preliminary workforce capacity estimate has been made based on data in the public realm. This capacity estimate is also put into context relative to the current supply of graduates from relevant degree programs. These estimates can be updated in the future with the assistance of workforce data supplied by industry.

A number of people have contributed behind the scenes to the preparation of this report. Particular thanks goes to Kelisha Lyndon and Professor Stefan Williams at the Digital Sciences Institute, Adeline Williams in Defence, Strategy and Engagement at the University of Sydney, Dr Matthew Richardson at the Australian Space Agency (now Associate Professor at the University of Southern Queensland), Dr Brett Biddington at Biddington Research Pty Ltd, and Jenny Mitchell at Engineers Australia.

Professor Matthew J. Cleary,
The University of Sydney

March 2024.

Key Concepts



Capability Pillar

TIER 1
State-of-the-art (< 10 yrs)

Cutting-edge weapon platforms that have been developed and entered production within the last decade

TIER 2
Modern-competitive (10-20 yrs)

Solutions that have undergone multiple upgrades throughout two decades of operation

TIER 3
Dated (30-40 yrs)

May still be operational but approaching retirement or obsolescence

Capacity Pillar

TIER 1
Specialised workforce

Experts in the field of guided weapons holding a Doctor of Philosophy (PhD) or a research Masters (MPhil)

TIER 2
Professional Workforce

Personnel who engage directly with guided weapons systems on a daily basis, in research and development, design, and maintenance. This group primarily consists of professionals possessing a Bachelor degree or specialised technicians with expertise in the technical intricacies of these systems.

TIER 3
Vocational Workforce

Vocational employees who are guided weapons-aware. They generally hold diplomas or other certificates, and serve as technicians, draftsmen, tradespeople, and labourers, among others

Supply Chain

TIER 1
Primes

The system designers and integrators, and end-user distributors

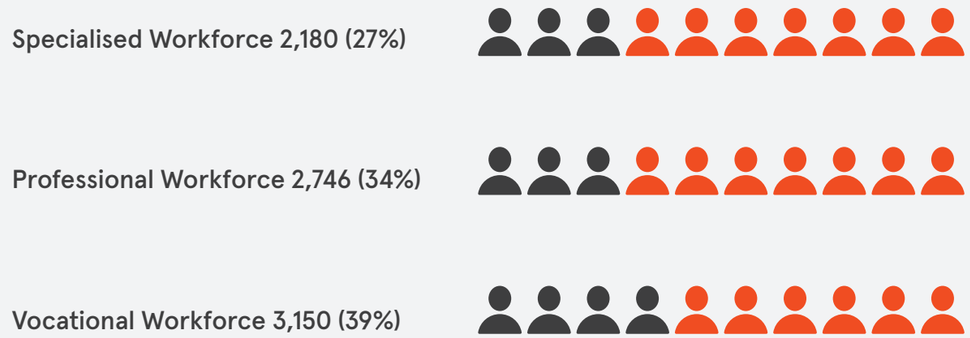
TIER 2
Suppliers

Primary suppliers which interact directly with the Primes and supply complete sub-assemblies, sub-systems, or components

TIER 3
Sub-suppliers

Sub-suppliers, who provide raw materials and sub-components directly to the Tier 2 suppliers

GWEO Workforce by Roles



Contents

1. Introduction

The Defence Strategic Update 2020[1] emphasised the need for Australia to improve its resilience to external interference and global disruption, operating at reduced warning times, and increased self-reliance. This was in response to recognition of the changing strategic circumstances and geopolitical landscape surrounding Australia.

The update emphasised the need for Defence to increase the range and quantity of the weapon stocks it holds, as well as explore the development of domestic manufacturing capabilities for advanced guided weapons and explosive ordnance, their base components, and their associated systems.

Soon after, the Australian Government announced the establishment of the Guided Weapons and Explosive Ordnance (GWEO) Enterprise led by Three Star serving officer, Air Marshal Leon Phillips OAM. A seed investment of AUD 1 billion was pledged as part of a broader AUD 270 billion ten-year investment in the Australian Defence Force (ADF) and the defence industry.[2] In 2022, the Australian Government announced that Lockheed Martin and Raytheon would join GWEO as Strategic partners to begin domestic missile assembly and production by 2025.[3] The initial strategy adopted by the Government aims to leverage the trilateral security AUKUS[4] partnership to Australian entities. The Australian Missile Corporation (AMC)[5] and Aurecon[6] have been appointed as Australian-based Enterprise Partners to GWEO.

Recent releases of the Defence Strategic Review[7] and the Defence Industry Development Strategy[8] indicate that the Commonwealth Government is committed to strengthening Australia's ability to design, manufacture, maintain, operate, upgrade, and ultimately dispose of guided weapons systems. However, a successful initiative requires clear direction to guide industry, policy, and academia. In essence, the amount of resources Australia is prepared to invest to build a 'sovereign capability' must be specified, along with a consideration of the corresponding opportunity costs the nation is willing to forgo. Three baseline scenarios are conceivable:

1. **Scenario 1.** Due to loss of warning time, import all missile systems from strategic partners. Australia's sovereign contribution would be limited to operations, including maintenance, repair, overhaul, and upgrade services.
2. **Scenario 2.** A transfer of technology model whereby Australia's sovereign contribution would include manufacturing and assembling of missile systems using existing, generally foreign owned, intellectual property.
3. **Scenario 3.** A resilient sovereign GWEO industry with substantial local manufacturing, but with continued dependence on the global supply chain for base components.

In each scenario, the realisation of a sovereign guided weapons enterprise is contingent on the rapid expansion of Australia's industrial base and technical workforce, a critical impediment at present. We seek to determine an independent, publicly available, scenario based estimate of the size and composition of the required workforce, enabling the ability to plan, build, and grow the required capacity for a self-reliant guided weapons initiative. The estimate is based on acquisition trends over the past two decades and using specific data for 2022. The study herein only considers scenario three which can be interpreted as our perspective on the long-term ambition for the nation. Thus, the objectives of this study are three-fold:

- To develop an accepted methodology for estimating the required Australian workforce to sustain a sovereign guided weapons manufacturing capability.
- To apply the developed methodology, using reasonable assumptions and data in the public realm, to make a preliminary estimate of the required workforce.
- To evaluate the current workforce capacity gaps, by comparing the estimated workforce requirement against the available talent pool in Australia.

Definitions used in this study are provided in Section 2. This is followed by an overview of historical trends in ADF acquisitions (Section 3). Then in Section 4 we develop the estimation methodology based on a linear model that enables forward projection based on macro trends. The preliminary estimate of workforce with breakdowns by sector and education is presented in Section 5.

The current workforce capacity gap in Australia is also quantified.

It is hoped that this work will contribute towards sensible planning and improved strategic policy.

2. Definitions

2.1 Capability and Capacity

The following definitions are used herein to distinguish the commonly-interchangeable terms *capability* and *capacity*:

- Capability: Having the technology, facilities and legal entitlement to manufacture and maintain guided weapons in country.
- Capacity: Having a workforce of the required size and with the required education, qualifications and experience to manufacture and maintain guided weapons in country.

2.2 Three-tier Pillar Structure

Figure 1 proposes a tiered structure encompassing the three themes that are deemed essential when defining a sovereign guided weapons enterprise, namely; capability, supply chain, and capacity. Capability encompasses the ability to manufacture and maintain weapon systems of different complexities and state-of-the-art classifications. Three tiers sub-divide the capability pillar. Tier 1 represents cutting-edge weapon platforms that have been developed and entered production within the last decade. Tier 2 are modern-competitive solutions that have undergone multiple upgrades throughout two decades of operation.Tier 3 are older systems with 30 to 40 years since introduction to service, and may still be operational but approaching retirement or obsolescence. This weapon system classification is consistent with Chapter 4 of the OE Data Integration Network (ODIN) TC 7-100.4, *Hybrid Threat Force Structure Organization Guide.*

The capacity pillar delineates the composition of the workforce and associates tier categories by tertiary qualifications. In this framework, Tier 1 represents specialised workforce; experts in the field of guided weapons holding a Doctor of Philosophy (PhD) or a research Masters (MPhil)[†]. Tier 2 identifies personnel who engage directly with guided weapons systems on a daily basis, in research and development, design, and maintenance. This group primarily consists of professionals possessing a Bachelor degree or specialised technicians with expertise in the technical intricacies of these systems. Tier 3 encompasses vocational employees who are guided weapons-aware. They generally hold diplomas or other certificates, and serve as technicians, draftsmen, tradespeople, and labourers, among others.

	Capability	Supply Chain	Capacity
Tier 1	State-of-the-art (< 10 years)	Primes	Specialised
Tier 2	Modern-competitive (10-20 years)	Suppliers	Professional
Tier 3	Dated (30-40 years)	Sub-suppliers	Vocational

Figure 1: Three-tier pillar structure for capability, supply chain and capacity.

The supply chain pillar bridges capability and capacity and describes the company types which make up the industrial sector. Tier 1 suppliers are the Primes, which are the system designers and integrators, and end-user distributors. In Tier 2 lie the primary suppliers which interact directly with the Primes and supply complete sub-assemblies, sub-systems, or components. Tier 3 are the sub-suppliers, who provide raw materials and sub-components directly to the Tier 2 suppliers. In the context of guided weapons, this supply chain hierarchy can be visualised in Figure 4

Note that there is no implied horizontal link between the tiers in the three pillars depicted in Figure 1. More so, for each guided weapon system associated to a capability, there exists a supply chain that can be broken down by the three supply chain tiers. Likewise, for each associated business, a capacity hierarchy based on specialised, professional, or vocational tiered workforce classifications exists.

[†] Coursework Masters qualifications in Australia are not as prevalent as they are in Europe, particularly in Engineering. While an MPhil would likely equip individuals with a sufficient level of specialised expertise to warrant classification as a Tier 1 worker, coursework Master qualifications are better categorised as Tier 2.

2.3 Sovereignty in Australia's Guided Weapons Enterprise

Australian sovereignty, in the context of guided weapons, involves securing access to and control over a necessary guided weapon capability. A spectrum of sovereignty, depicted in Figure 2, correlates with the level of resources Australia is willing to invest. With minimal investment (full global reliance), sovereignty is maintained through a resilient supply chain capable of functioning despite disruptions.[9] However, increasing national investment allows for sovereignty through local design, manufacturing, and production of guided weapon systems, achieving independence from foreign expertise, trade, regulation, or interference (full self-reliance). The three scenarios proposed in Section 1, are representative of a gradual increase in national investment. Choosing a position on this spectrum necessitates weighing corresponding opportunity costs and is influenced by evolving national circumstances and government priority.

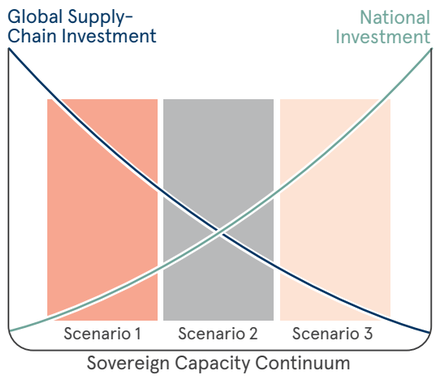


Figure 2: Trade-off between national investment and global supply-chain dependence for different levels of sovereign capability and capacity.

Estimating the required workforce requires accepting a position on the sovereignty spectrum. In this context, scenario three, i.e. sovereignty through a resilient local GWEO industry, which is dependent on the global supply chain for base components, is more precisely defined. One can survey international companies who manufacture guided weapons systems, and estimate Australia's needs through appropriate scaling. Conversely, to undertake a similar procedure based on complete global-reliance, one must have an intimate knowledge of what specific weapons systems are being acquired, in what quantity, and under what circumstances. This level of understanding is not possible with information available in the public domain.

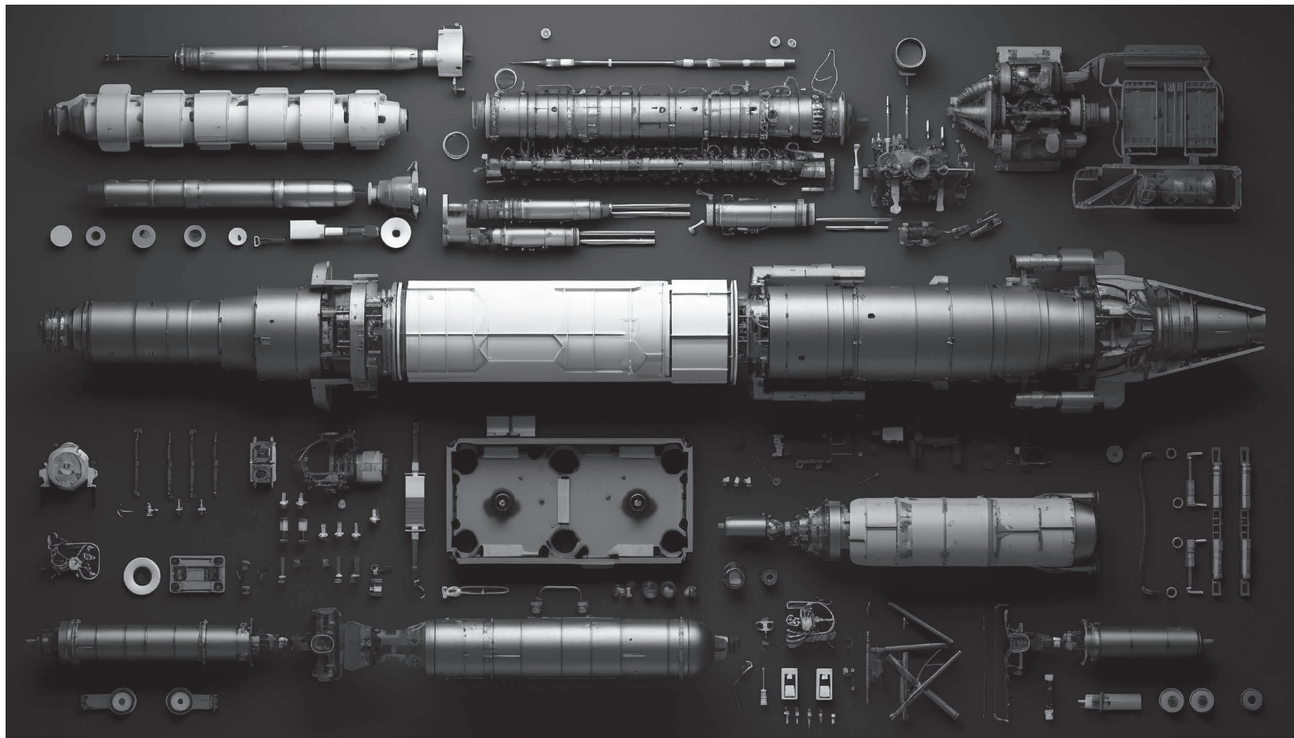


Figure 3 illustrates a typical guided weapon system. As shown, each platform can be segmented into four general sub-assemblies; (1) propulsion, (2) warhead and fusing, (3) guidance, navigation and control, and (4) seekers and processing. Within each sub-assembly, there are a number of critical sub-systems. In the context of scenario three, any entity engaged in activities spanning research, design, production, deployment, operation, and retirement of a critical system, is the responsibility of the local Australian GWEO industry. This would correspond to Supply Chain Tiers 1 and 2 in Figure 4 (i.e. Primes and Suppliers). On the other hand, base components and raw materials are categorised as the responsibility of the broader global supply chain (Tier 3 Sub-suppliers in Figure 4). The global supply chain may involve Australian-based companies but their being located in country is not assumed in our analysis.

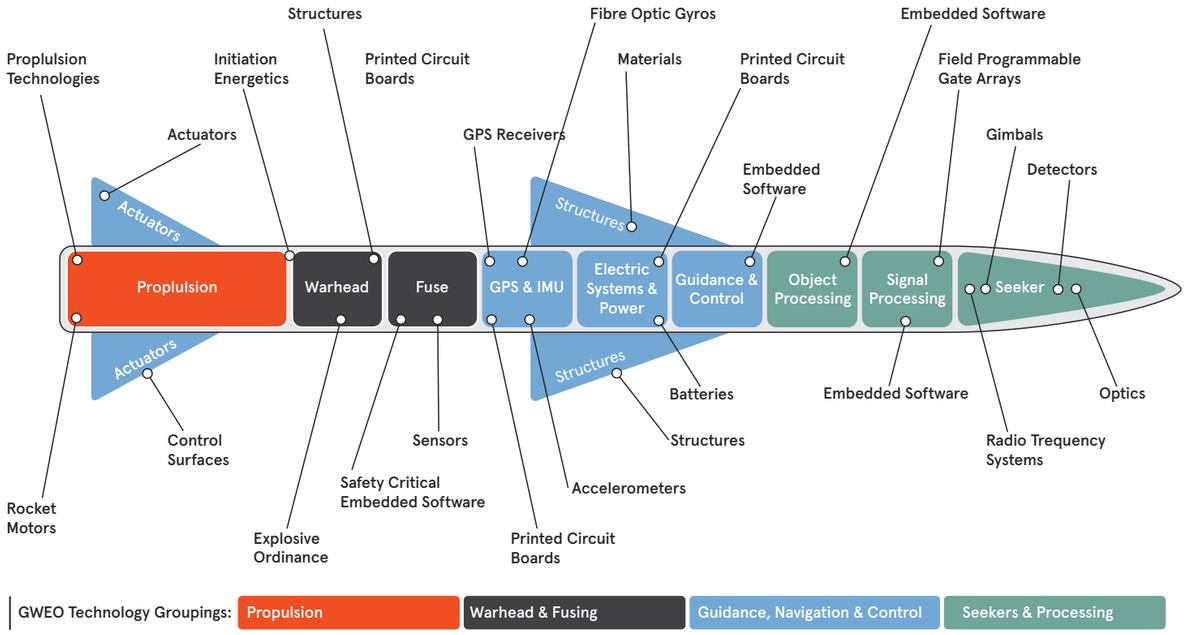


Figure 3: Breakdown of a guided weapon by subsystem. Adapted from Robinson.[10]

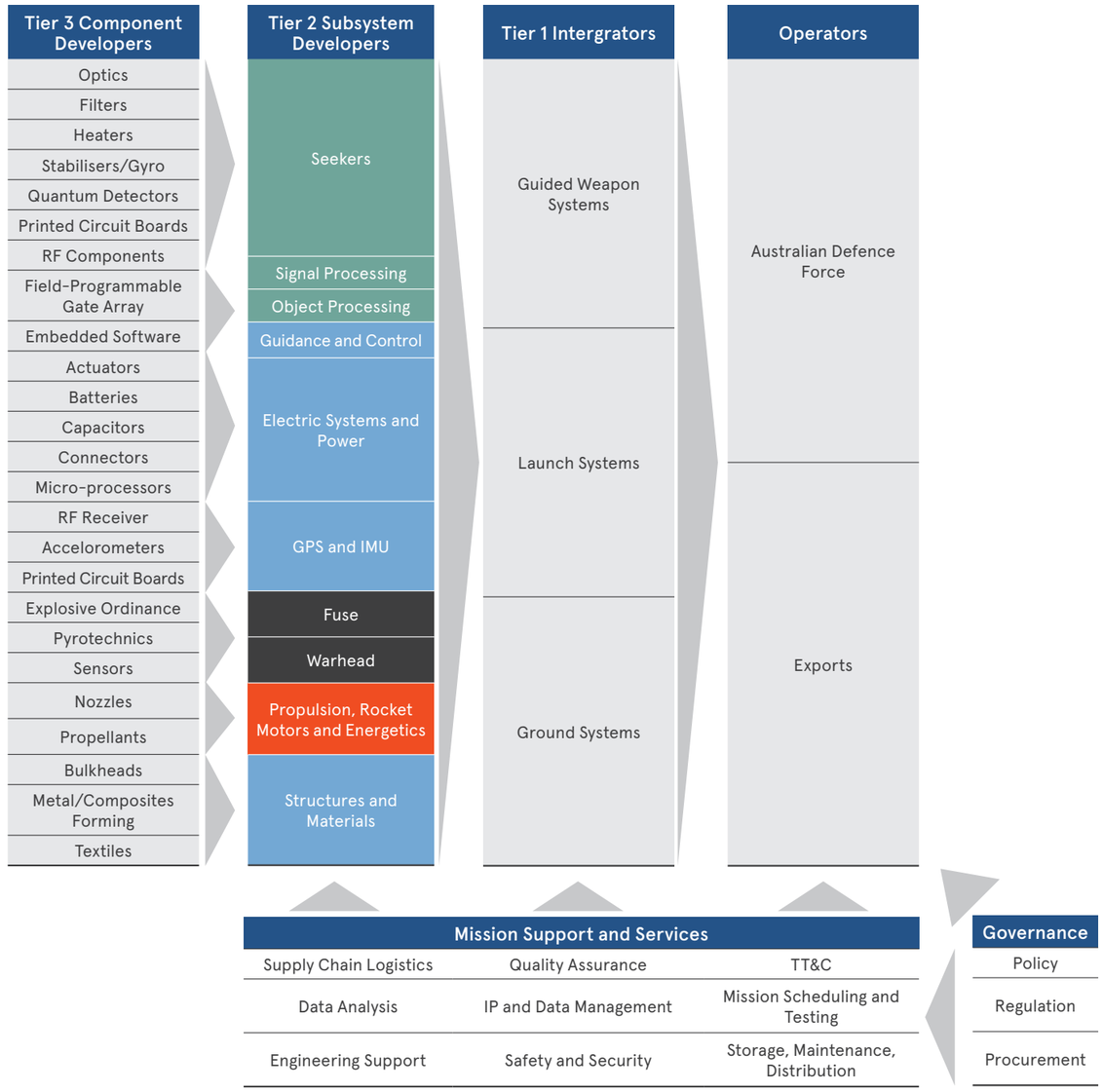


Figure 4: Supply architecture for guided weapon systems. Adapted from Biddington.[11] Colour coding as per Figure 3

3. ADF Guided Missile Acquisitions 2004–2022

This section provides an overview of the historical trends in Australian Defence Force acquisitions of guided weapon systems over a period of approximately two decades.

A database of ADF guided weapons acquisitions is generated by sourcing public media releases which confirm a contract of sale,[9, 12] which are primarily from US-based primes. Specifically, only guided weapon systems are considered, and the expenditure is catalogued by press release year. The subsequent historical trend is shown in Figure 5. As observed, ADF acquisitions have a high annual variability, with surge years such as 2009, 2014, 2016, and 2021, as well as null years such as 2005–2007, 2012, and 2018. The overall trend is however clear, with expenditure in guided weapon acquisitions increasing four-fold over the last two decades.The source of variability is likely linked to the broader ADF strategy, and classified acquisitions that are not reported.

Predicting future expenditure is very difficult. A linear model produces an imperfect fit to the historical data, as shown in Figure 5. Nevertheless, it is convenient to assume a smooth annual expenditure to make estimates of workforce capacity. A somewhat steady acquisition program would also contribute to sustainability of the industry, similar to the strategy adopted for domestic defence shipbuilding, as announced in the National Naval Shipbuilding Enterprise.[13] In doing so, plans can be made to establish and sustain a critical mass of technically skilled employees to support a sovereign guided weapons enterprise.

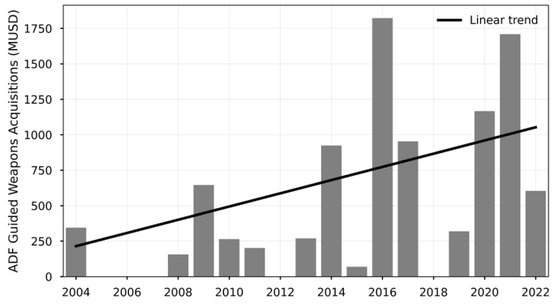


Figure 5: Estimated ADF Guided Weapons Acquisitions between 2004 and 2022. MUSD Millions of US dollars.

A range of missile systems are required for different defence platforms and potential combat use-cases, such as; air-to-air, air-to-surface, surface-to-surface, etc. The concept of a 'missile matrix' is well-described by the Australian Strategic Policy Institute (ASPI),[14] which categorises guided weapon systems by launch platform and target class. Using the Capability tiers, defined in Figure 1, a condensed classification of the missile matrix is presented in Table 1. The ADF predominantly focuses on Tier 2 systems (at least 23 unique platforms), followed by Tier 1 and Tier 3 with eleven and three unique acquired or proposed platforms, respectively. All systems in Table 1 can be attributed to 13 prime manufacturers, of which 31% are based in the US, 54% in Europe, and 15% in the Middle East or Asia. Although a large portion of guided weapon systems in use by the ADF are sourced from European manufacturers, on average, approximately 87% of annual expenditure is associated to three US-based Primes (Raytheon, Lockheed Martin, and Boeing).

Capability	Guided Weapon Platform	Manufacturer
Tier 1	SM-3/ Aegis Ashore	Raytheon, Aerojet, MHI
	JSM	Kongsberg
	IDA	Diehi/Roketsan
	Precision Strike Missile, Hellfire	Lockheed Martin
	JASSM-ER, LRASM	
	GBU-53B, SM-6, Tomahawk Block V	Raytheon
Tier 2	SBD, GBU-39, Harpoon, JDAM	Boeing
	Mk-48, 54 Torpedo, AGM-88, AGM-9X	Raytheon
	SM-2, JSOW, AIM-20 AMRAAM	
	ESSM	Raytheon / BAE Systems
	NSM	Kongsberg
	THAAD, JASSM, ATACMS, GMLRS	Lockheed Martin
	Patriot	Raytheon/ Lockheed Martin/ Boeing
	Brimstone	MBDA
	Spike LR2	Rafael Adv. Defence Systems
	Javelin	Raytheon/ Lockheed Martin
Tier 3	MU Torpedo	Euro Torp
	AIM-92 Stinger	Raytheon/ Lockheed Martin
	RBS-70	Saab AB

Table 1: Australia's Missile Matrix based on historical ADF acquisitions 2004 - 2022 and potential platforms for future capability. Note that company involvements in particular projects change over time and the table is based on our best attempt with available public data.

4. Methodology

Workforce estimation requires detailed knowledge of the industry's current and historical composition, including a breakdown by qualification levels. Conventionally, a bottom-up approach is used, which estimates the workforce from the individual supplier level, adding detail through evaluation of contributing labour pools and adjoint markets. An alternative is to estimate the workforce by evaluating the macro trends, starting with the Primes, then working down the supply chain. This approach inherently relies on scenario-based mapping and first-order approximations, however, it can enable the use of global data to estimate the domestic workforce through appropriate scaling. The guided weapons sector, much like the broader defence industry, is reserved with its information sharing. Attempts to estimate future workforce capacity in this industry, especially when it involves establishing a new enterprise in Australia, will have a higher level of uncertainty than estimates for other less sensitive industries. Therefore, this work applies the second methodology based on global data for Primes. This approach produces a conceptually simple framework that can be scaled as assumptions about sovereign capability and national requirements are refined. The assumptions and limitations are explicitly stated below.

4.1 Portfolio of Sovereign Manufactured Guided Weapons

The first step is to nominate a selection of guided weapon systems that will be locally manufactured. Since the Australian government has not publicly announced such a portfolio, we assume it and, naturally, the workforce estimation will vary as that assumption is refined in the future. In the near term (less than five years) the most likely outcome of GWEO will be licensing of Intellectual Property from existing international Primes. The following resources are used to hypothesise a likely guided weapons portfolio:

1. The missile matrix in Table 1
2. Recommended guided weapons portfolio from ASPI [14]
3. GWEO announcements [15, 16]
4. Disclosure by GWEO partners [17]
5. Recommendations from RAND Australia [9]

The resulting portfolio consists of seven unique guided weapon platforms from six global prime manufacturers, as shown in Table 2. The majority of the selected systems are modern-competitive solutions (Tier 2) with multiple iterations over the last two decades. This reflects the likeliness for IP transferal to Australia to occur for non state-of-the-art platforms (Tier 1). The GMLRS and Spike LR2 missiles have been publicly announced as candidates for GWEO.[15, 16] The remaining platforms from Kongsberg, Raytheon, Boeing, and MBDA are selected due to historical ADF acquisition expenditure and existing industry presence in Australia. Although the exact weapon systems that are locally manufactured may be subject to change, the list of Primes is likely to stay relatively constant.

Weapon Platform	Capability Tier	Manufacturer	1st Year of Service
JSM	1	Kongsberg	2010's
NSM	2	Kongsberg	2012
ESSM	2	Raytheon / BAE	2004
GMLRS	2	Lockheed Martin	2005
JDAM	2	Boeing	1999
Brimstone	2	MBDA	2005
Spike LR2	2	Rafael (VRA)	2000's

Table 2: A Guided Weapon Portfolio for Sovereign Manufacture.

4.2 Tier 1 Prime Workforce

A global workforce productivity metric is introduced:

$$\texttt{Revenue-per-Employee} = \frac{\texttt{Annual Revenue}}{\texttt{Number of Employees}} \quad (1)$$

Assuming that this metric has the same value in Australia as it does globally, the sovereign Tier 1 workforce size is estimated as

$$\texttt{Required Tier 1 Prime Workforce} = \frac{\texttt{ADF Acquisitions}}{\texttt{Revenue-per-Employee}} \quad (2)$$

Equations (1) and (2) are applied to find values for **Revenue-per-Employee** and **Required Tier 1 Workforce** for each Prime listed in Table 2. Global or single country annual revenue and number of employees in the guided weapons division can sometimes be extracted from publicly available annual financial reports. In some cases, the guided weapons division is embedded within a larger division, i.e. 'missiles and defence'. In such a case, data for the parent division can be used. Where such information is not made publicly available, surveys and interviews may be used (see sample survey questions in Appendix A). Finally, the total **Required Tier 1 Workforce** for Australia is then obtained by averaging the results over all of the Primes in the portfolio. The accuracy of this approach will generally improve as the number of Primes increases.

4.3 Tiers 2 & 3 Supplier Workforce

Continuing with the top-down methodology, the process for estimating the Tiers 2 & 3 (Suppliers & Sub-suppliers) workforce is as follows:

1. Let the **Number of Tier 1 Primes = P**. This is given in Table 2. Each Prime is given an index i.
2. Determine the **Percent Tier 1 Prime Business in Guided Weapons = A_i**. This can be obtained by revenue associated with guided weapons.
3. Determine the **Number of Tier 2 & 3 Suppliers per Prime = B_i**. Such information is sometimes disclosed in annual financial reports or can be obtained by surveys and interviews (see sample survey questions in Appendix (A). Each Tier 2 or Tier 3 supplier is given an index j.
4. Determine the **Number of employees per Tier 2 or Tier 3 Supplier = C_{ij}**. Here we propose using the following statistical breakdowns [18, 19] (although other methods are also possible):
   - 28.5% of suppliers are large companies with an average of 500 employees.
   - 31.5% of suppliers are medium companies with an average of 250 employees.
   - 40% of suppliers are small companies with an average of 50 employees.
5. Determine the **Percent Tier 2 & 3 Supplier Workforce in Technical Roles = D_{ij}**. Here we assume the following statistical breakdowns (but future confirmation is required):
   - 50% of employees in large companies have technical roles.
   - 65% of employees in medium companies have technical roles.
   - 80% of employees in small companies have technical roles.
6. Determine the **Percent Tier 2 & 3 Supplier Workforce in Australia = E_{ij}**. Here, we assume that a distinct Tier 2 or Tier 3 Australian supplier is responsible for delivering each of the ten critical subsystems outlined in Fig. 4.
7. Determine the scaling factor associated with Australian sovereign capacity for each Tier 1 Prime:

$$\texttt{ADF Scaling Factor} = \frac{\texttt{ADF Acquisitions}}{\texttt{Prime Guided Weapon Revenue}} = F_i$$

8. Calculate the Tier 2 & 3 workforce in Australia:

$$\texttt{Required Tiers 2 \& 3 Supplier Workforce} = \sum_i^P \left(A_i \sum_j^{B_i} \left(C_{ij} \times D_{ij} \times E_{ij} \right) \times F_i \right) \quad (3)$$

4.4 Workforce by Qualification

In order to determine required Australia's sovereign labour breakdown by qualification, the statistics published by Kongsberg[20] are used here (but other diverse sources of data should be used in future):

- 27% of technical employees are PhD or Masters qualified[†]
- 34% of technical employees are Bachelors qualified or technicians with advanced qualifications
- 39% of technical employees are vocational workers.

4.5 Assumptions and Limitations

The workforce capacity estimation method outlined in Sections 4.2 and 4.3 has several underlying assumptions some of which were briefly addressed in those sections. Table 3 states all of the assumptions, their justification and the resulting limitations of the method. Many of the limitations can be significantly reduced with estimations made using data from multiple Primes.

Assumption	Justification	Limitation
Tier 1 Primes:		
An average `Revenue-per-Employee` is used in Equation 1. This is all employees in the company or division.	`Revenue-per-Employee` is a common benchmarking tool used in multiple industries for high-level estimation and strategic planning[19]	(i) Overlooks the societal, cultural, and geographical factors that impact workforce productivity. (ii) `Revenue-per-Employee` is not specific to technical employees.
Scaling of the workforce to Australia in Equation 2 is achieved through revenue from sales to Australia.	This is the closest estimate that can be achieved without obtaining classified statistics of national sales for each prime.	Overlooks individual system complexity, as Primes provide diverse products and services with varying labour or supply chain needs, during the platform lifecylce. Result is likely an over-estimation, as revenue from sales to Australia accounts for more than just the guided weapon platform acquisition.
Missing statistics are approximated with the next-best available information. This applies to revenue and workforce figures for Primes and their guided weapon business segments.	The structure of financial reporting is highly inconsistent for different nations. A lot of gaps in the statistics sourcing eventuate, so approximation is a reasonable tool for workforce estimation	Errors in the revenue and workforce statistics propagate linearly.
Tier 2 & 3 Suppliers:		
The ratio of *large : medium : small* companies in the supply chain is assumed constant for each prime, explicitly *large : medium : small* = 29 : 31 : 40%	These values are adopted from a KPMG report analysing the economic contribution of Lockheed Martin to Australia.[18]	(i) These values might not be representative of the other Primes. (ii) The supply chain ratio is defined for the total suppliers, thus the break down might not be representative of the guided weapon division.
The number of employees per *large : medium : small* supplier is assumed constant, with an average of *large : medium : small* = 500 : 250 : 50 employees.	These values were adopted from market analysis in global military aircraft and aerospace manufacturing.[19]	(i) The average number of employees per company size is not specific to guided weapon companies alone. (ii) Relying on averages could potentially introduce bias.
The percentage of employees in technical roles of *large : medium : small* suppliers is assumed constant, at *large : medium : small* = 50 : 65 : 80%	These ratios are a guess	The number of technical employees is contingent on both the nature of the product and the individual company. Therefore, utilising averages is likely a misrepresentation.
100% of the suppliers workforce is involved in supporting the Prime for the duration of the contract.	These ratios are a guess	This is invariably inaccurate. Typically, a supplier allocates a fraction of its resources to a single contract, servicing multiple contracts concurrently.
Scaling the global supply chain workforce to Australia is done through linear scaling of ADF acquisitions over the primes total GW revenue.	This is a guess	This approach overlooks the societal, cultural, and geographical factors that impact systems, processes, and workforce productivity. Moreover, this scaling mechanism may significantly underestimate the number of suppliers needed. Given that guided weapon systems are highly complex, the number of suppliers does not exhibit a linear relationship with acquisitions. For example, the [19] quantity of GW systems typically is independent of the number of components required to construct a single guided weapon system.
There are ten suppliers who produce Tier 2 systems (outlined in Figures 3 and 4), whose workforce is assumed to be in Australia	This is a guess	It is likely that sub-assemblies of Tier 2 systems are outsourced to sub-suppliers with the relevant expertise, inflating the required workforce. Likewise, multiple suppliers could compete for the same OEM contract,fosteringinnovation and efficiency. The monopolistic supply structure for mission critical systems neglects these factors, however provides a minimum viable workforce.
Workforce Qualification:		
Estimating the workforce tiers is achieved by assuming a constant ratio of *specialist : professional : vocational* = 27 : 34 : 39%	These values are adopted from a Kongsberg report detailing their workforce statistics.[20]	Kongsberg might not be representative of the other Primes or Tier 2 suppliers. Likewise, the workforce statistics are defined for the total company, thus might not be representative of the guided eapon division.

Table 3: Workforce methodology assumptions, justification, and limitations

[†]The data does not distinguish between research Masters (MPhil) and coursework Masters (e.g. ME or MSc). Coursework Master qualifications are best categorised as Tier 2 and this lack of distinction in the data skews the results.

5. Preliminary Workforce Estimations

Here a preliminary workforce estimation is made using the methodology described in the previous section. At this stage, no surveys or interviews have been conducted and the estimation has been made using publicly available data. Data was not available for all of the Primes listed in Table 2 and the preliminary estimate is therefore made with a subset for which data could be found.

5.1 Preliminary Estimation of Tier 1 Prime Workforce

The required parameters for estimating the Prime workforce according to Equations (1) and (2) are shown in Table 4. Due to lack of publicly listed information for MBDA and Rafael Advanced Defence Systems, they were omitted from the **Revenue-per-Employee** and ADF Acquisition expenditure figures and subsequent workforce estimation calculations.

Company	Revenue-Per-Employee (MUSD/person)	ADF Acquisitions (MUSD)
Lockheed Martin	0.5688	235.0
Kongsberg	0.3226	60.7
Raytheon	0.4815	1,514.0
Boeing	0.4263	305.0

Table 4: Data for Tier 1 Prime workforce. Data is for 2022.[12, 14, 20-23]

Using Equation (2) and averaging over the companies listed in Table 4 we arrive at

Required Tier 1 Prime Workforce = 6,691

The largest contribution to this figure is from Raytheon, due to higher revenue from sales to the ADF in the Year 2022 compared to the other primes. A longitudinal study may reveal different results in different years.

5.2 Preliminary Estimation of Tier 2 & 3 Supplier Workforce

The estimation is calculated according to Equation (3). The parameters relevant to the Primes are shown in Table 5. Note that data is available for only four Primes (P = 4) at this stage.

The Supplier parameters in Equation (3) are obtain a follows. C_{ij} and D_{ij} are given by the statistical breakdowns listed in Section 4.3 under Steps 4 and 5, respectively. Parameters E_{ij} are less certain. For simplicity and due to a lack of sufficient data at this stage, we set E_{ij} = constant for all Primes and Suppliers and give results for two different constant values.

Primes, i	A_i	B_i	F_i
Lockheed Martin	17.2	16,000	0.4
Kongsberg	7.0	9,000	2.4
Raytheon	22.2	14,000	2.3
Boeing	5.2	12,000	2.4

Table 5: Data for Tier 2 & 3 Supplier workforce. Data is for 2022.[20-23]

1. Assuming the entire Tier 2 & 3 Supplier workforce is in Australia, E_{ij} = 100%, gives:

   Required Tiers 2 & 3 Supplier Workforce = 22,860

   Using the statistical breakdowns listed in Section 4.3 under Step 4, this workforce would be distributed across 165 Tier 2 & 3 Supplier businesses. Of these 47 are large sized companies, 52 are medium sized and 66 are small sized. Under this scenario, the total (Tiers 1, 2 & 3) guided weapons workforce size based on available 2022 data is 6,691 + 22,860 = 29,551.

2. Assuming there are just ten unique Tier 2 or Tier 3 Suppliers for the critical subsystems listed in Figure 4, rather than 165, corresponds to E_{ij} = 10/165 = 6.1%, giving:

   Required Tiers 2 & 3 Supplier Workforce = 1,385

   Under this scenario, the total (Tiers 1, 2 & 3) guided weapons workforce size based on available 2022 data is 6,691 + 1,385 = 8,076.

5.3 Preliminary Estimate of Workforce by Qualification

With a Tier 1 Prime workforce of 6,691 employees, and a sovereign Tier 2 & 3 Supplier workforce of 1,385 employees, using the qualification statistical distribution listed in Section 4.4, the estimated workforce composition is as per Figure 6.

Two caveats must be mentioned here. Firstly, due to the lack of distinction in the single reference data point, the Specialised workforce estimate includes PhD, MPhil and coursework Master graduates. The last of these would be better classed as Professional workforce and the estimate requires future adjustment as more data is made available. Secondly, certain variations in the focus of Australia's guided weapons capability are likely to significantly vary the distributions in Figure 6. For example, an industry that had a stronger focus on supporting US production of existing, proven US owned platforms would skew the distribution more towards Vocational qualifications.

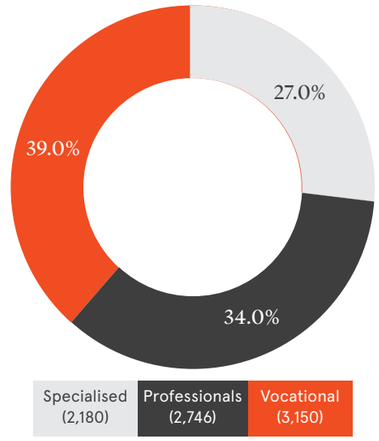


Figure 6: Total sovereign guided weapons workforce breakdown by qualification

5.4 Context of Preliminary Workforce Estimates

Here, the preliminary workforce estimates are discussed in the context of current engineering graduation numbers. The methodology is illustrated by Figure 7. International student graduates and skilled migrants are not considered in the analysis due to the national security issues involved. Tier 3 Vocational workers are not considered in this preliminary study.

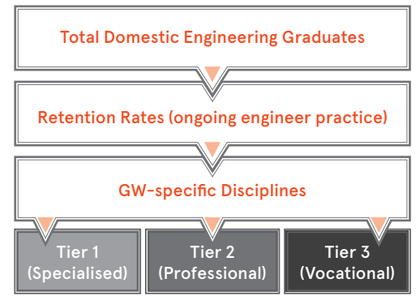


Figure 7: Methodology for determining workforce capacity gaps via tiers Table 6 summarises the findings

Total domestic engineering graduate numbers are found in Table 6 using data from.[24] This is reduced based on a engineering career retention rate of 80%.[24, 25] Using the statistical distributions for different categories of engineering graduates,[26] numbers are compiled for Systems Engineering, Mechanical Engineering, Electrical Engineering, and Aerospace Engineering. Other engineering disciplines may be important, e.g. chemical engineering, and might be considered in future estimations.

In 2019 there were just 302 Tier 1 Specialised graduates. The required workforce numbers are 2,180. Assuming, rather optimistically, that 50% went into the guided weapon industry, it would take about 15 years to build up this workforce from scratch. The number of Tier 2 Professional graduates appears to be more promising but, given strong competition from other sectors of the economy, the number going to the guided weapon industry is likely to be rather small unless strong incentives are put in place. Assuming just 10% of Tier 2 graduates went into the guided weapon industry, it would take 7 years to build up this workforce. Once again it is noted that advanced vocational qualified workforce has not been estimated at this point in time and thus the Tier 2 numbers are subject to some additional uncertainty.

	Tier 1 Specialised		Tier 2 Professional			
	Doctorate	Research Masters	Coursework Masters	Other Postgrad.	Bachelor	Diploma/ Other Undergrad.
Specialty:						
Systems Engineering & Engineering Related Technologies:	145	17	264	130	1709	192
Mechanical Engineering &Technology:	35	4	64	3	414	46
Electrical/Electronics Engineering & Technology:	57	7	104	51	674	76
Aerospace Engineering & Technology:	33	4	60	29	387	43
Total	270	32	492	241	3184	357
	302		4274			

Table 6: Domestic engineering graduates in engineering disciplines relevant to guided weapons. Data is for 2019. [24]

References

1. Defence, 2020 Defence Strategic Update (2020).
2. Prime Minister, Minister. for Defence Industry, Minister. for Industry, Science and Technology, Morrison Government accelerates Sovereign Guided Weapons manufacturing (2021).
3. Australian Government, Australia takes next step to delivering Guided Weapons and Explosive Ordnance Enterprise , available at https://www.minister.defence.gov.au/media-releases/2022-04-05/ australia-takes-next-step-delivering-guided-weapons-and-explosive-ordnance-enterprise (2022).
4. Australian Submarine Agency, AUKUS Nuclear-Powered Submarine Pathway, available at https://www.asa.gov.au/aukus (2023).
5. Australian Missile Corporation, AMC Locked in for GWEO Enterprise , available at https://www.amc.com.au/latest-news/amc-locked-in-for-gweo-enterprise (2022).
6. Aurecon Group, Aurecon appointed as the inaugural Guided Weapons and Explosive Ordnance Enterprise Partner, available at https://www.aurecongroup.com/about/latest-news/2022/september/aurecon-enterprise-defence-partnership (2022).
7. Defence, National Defence: Defence Strategic Review (2023).
8. Defence, Defence Industry Development Strategy (2024).
9. C. A. Mouton, C. Rhodes, M. V. Arena, P. DeLuca, A. Dowse, J. P. Godges, A. R. Grissom, C. Lucas, E. Silfversten, Establishing a Sovereign Guided Weapons Enterprise for Australia: International and Domestic Lessons Learned, RAND Corporation, Santa Monica, CA, 2022. doi:10.7249/RRA1710-1.
10. K. Robinson, ARC Industrial Transformation Traning Centre, Co-Design Workshop 2, in: Industry Co-desin Workshop 2: ARC Industrial Transformation Training Centre for Propulsion Systems and Launch Capabilities, 2023.
11. B. Biddington, Conversation in GWEO soverignty (2023).
12. Defence Security Cooperation Agency, Major Arms Sales, available at https://www.dsca.mil/ press-media/major-arms-sales (2023).
13. Australian Government, National naval shipbuilding enterprise: Naval shipbuilding plan, available at https://www.defence.gov.au/business-industry/naval-shipbuilding/plan (2023).
14. M. Hellyer, Cracking the missile matrix: The case for Australian guided weapons production, Australian Strategic Policy Institute (2021).
15. A. P. D. Reporter, Defence chooses RAFAEL for GWEO acquisition, available at https://www.asiapacificdefencereporter.com/defence-chooses-rafael-for-gweo-acquisition/ (2023).
16. AuManufacturing, Australia will make its own missiles in 2025 – Conroy, available at https://www.aumanufacturing.com.au/australia-will-make-its-own-missiles-in-2025-conroy (2023).
17. Australian Government, Guided Weapons and Explosive Ordnance Enterprise: Strategic and Enterprise Partners, available at https://www.defence.gov.au/business-industry/industry-capability-programs/guided-weapons-explosive-ordnance-enterprise (2023).

18. KPMG Australia, The Economic Contribution of Lockheed Martin to Australia (2018).

19. S. Al Bari, Global Military Aircraft & Aerospace Manufacturing, available at https://www.my.ibisworld.com/gl/en/industry/c2544-gl/at-a-glance (2023).

20. Kongsberg Gruppen, Annual Report and Sustainability Report 2022, available at https://www.kongsberg.com globalassets/corporate/investor-relations/annual-report-2022/ oppdatert-rapport3/kog-rapport-2022-gb-final-pdf-290323.pdf (2022).

21. Lockheed Martin Corporation, 2022 Annual Report, available at https://www.lockheedmartin.com/content/dam/lockheed-martin/eo/documents/annual-reports/lockheed-martin-annual-report-2022.pdf (2022).

22. Raytheon Technologies, 2022 Annual Report, available at https://investors.rtx.com/financial-information/annual-reports (2022).

23. The Boeing Company, 2022 Annual Report, available at https://investors.boeing.com/investors/reports/default.aspx (2022).

24. Australian Council of Engineering Deans (ACED), Australian engineering higher education statistics 2009 - 2019, available at https://www.aced.edu.au/downloads/ACED%20Engineering%20Statistics%20Dec%202020_v2.pdf (2020).

25. Engineers Australia, Statistics, available at https://www.engineersaustralia.org.au/about-engineering/statistics (2023).

26. Australia Bureau of Statistics, Australian Standard Classification of Education (ASCED), available at https://www.abs.gov.au/statistics/classifications/australian-standard-classification-education-asced/2001 (2001).

Appendix A Industry Survey

Section 1: Critical Data:

The questions in the following section are directly relevant to our workforce capacity model.
For each question bellow, we ask for annual information over a 5 year period between 2018-2022.
To ensure accurate data, we ask for exact numbers where possible

1. What was your company's total workforce?

2018: _____
2019: _____
2020: _____
2021: _____
2022: _____

2. What was your company's total workforce in Guided Missile Systems?

2018: _____
2019: _____
2020: _____
2021: _____
2022: _____

3. How many engineers are employed in Guided Missile Systems?

2018: _____
2019: _____
2020: _____
2021: _____
2022: _____

4. How many vocational workers are employed in Guided Missile Systems?

2018: _____
2019: _____
2020: _____
2021: _____
2022: _____

5. What was the company's total (global) revenue (MUSD)?

2018:

2019:

2020:

2021:

2022:

6. What was the company's revenue from sales to Australia (MUSD)?

2018:

2019:

2020:

2021:

2022:

7. What was the company's revenue attributed to Guided Weapon Systems (MUSD)?

2018:

2019:

2020:

2021:

2022:

8. What was the company's revenue from sales to Australia in Guided Weapon Systems (MUSD)?

2018:

2019:

2020:

2021:

2022:

9. How many global suppliers does your company engage with?

2018:

2019:

2020:

2021:

2022:

10. How many global suppliers does your company engage with for Guided Missile Systems?

2018:

2019:

2020:

2021:

2022:

Section 2: Detailed Breakdowns

This section aims to provide a detailed breakdown of workforce and supply chain data in order to populate our tiered structure.

For each question bellow, we ask for information over a year period i.e. 2021-2022, which is representative of annual statistics.

To ensure accurate data, we ask for exact numbers where possible, however ratio's or percentages are acceptable.

1. How many engineers employed in Guided Missile Systems have PhD qualifications?

2. How many engineers employed in Guided Missile Systems have Masters qualifications?

3. How many engineers employed in Guided Missile Systems have Bachelors qualifications?

4. How many engineers employed in Guided Missile Systems have Diploma qualifications?

5. How many engineers employed in Guided Missile Systems do not have tertiary qualifications?

6. How many Aerospace Engineers are employed in Guided Missile Systems?

7. How many Chemical Engineers are employed in Guided Missile Systems?

8. How many Electrical Engineers are employed in Guided Missile Systems?

9. How many Mechanical Engineers are employed in Guided Missile Systems?

10. How many Systems Engineers are employed in Guided Missile Systems?

11. How many Software Engineers are employed in Guided Missile Systems?

12. How many Environmental Engineers are employed in Guided Missile Systems?

13. How many IT (Cyber) Engineers are employed in Guided Missile Systems?

14. How many Mechatronics Engineers are employed in Guided Missile Systems?

15. How many Naval Engineers are employed in Guided Missile Systems?

16. How many Structural Engineers are employed in Guided Missile Systems?

17. How many vocational employees employed in Guided Missile Systems do not have tertiary qualifications?

18. How many engineers employed in Guided Missile Systems have more than 20 years experience?

19. How many engineers employed in Guided Missile Systems have between 10-20 years experience?

20. How many engineers employed in Guided Missile Systems have between 5-10 years experience?

21. How many engineers employed in Guided Missile Systems have less than 5 years experience?

22. How many vocational employees in Guided Missile Systems have more than 20 years' experience?

23. How many vocational employees in Guided Missile Systems have between 10-20 years experience?

24. How many vocational employees in Guided Missile Systems have between 5-10 years experience?

25. How many vocational employees in Guided Missile Systems have less than 5 years experience?

26. How many global suppliers for Guided Missile Systems are Original Equipment Manufactures (OEM) or Primes?

27. How many global suppliers for Guided Missile Systems are contractors or sub-contractors?

28. How many global suppliers for Guided Missile Systems are large businesses (ave. 500 employees)?

29. How many global suppliers for Guided Missile Systems are medium businesses (ave. 200 employees)?

30. How many global suppliers for Guided Missile Systems are small businesses (ave. 50 employees)?

31. How many global suppliers are used for more than one Guided Missile System project?

32. How many global suppliers are unique to one specific Guided Missile System project?

33. How many suppliers are responsible for providing mission-critical components, subsystems, sub-assemblies, and software for Guided Missile Systems?

Section 3: Additional Information

This section aims to understand external factors influencing Australia's workforce capacity. In some cases, exact numbers might not be known. Informed estimations are sufficient.

1. Do engineers employed in Guided Missile Systems partake in other cross-discipline domains within the company?

2. Do engineers employed in domains not related to guided missile systems partake in guided missile programs or projects?

3. How many Engineers are specialists in propulsion systems?

4. What is the turnover rate of engineers?

5. How many engineers were hired specifically to work in Guided Missile Systems?

6. How many vocational employees were hired specifically to work in Guided Missile Systems?

7. How many engineers working within Guided Missile Systems left the company or retired?

8. What is the average tenure of engineers in Guided Missile Systems?

9. What is the average tenure of vocational employees in Guided Missile Systems?

10. What is the retention rate of engineers who have completed internships programs within Guided Missile Systems?

11. Can you provide an estimate of the total number of employees across all global suppliers for a Guided Missile Systems who are directly involved in fulfilling contracts for your company?

12. What percentage of the workforce within your global suppliers is dedicated exclusively to contracts with your company?

13. How many suppliers are Australian Companies?

Section 4: Other Comments

Please provide any additional information which might be of relevance:

Section 5: Feedback

Please provide feedback on the questionnaire:

Get in touch

For more information or to contact Professor Matthew Cleary, please email: m.cleary@sydney.edu.au and dsi@sydney.edu.au

Digital Sciences Initiative
Faculty of Engineering
Level 5, Faculty of Engineering Bldg (J12)
The University of Sydney NSW 2006

To join the Australian Rocket Systems Training Network (ARSTN), please go to: https://dsi.sydney.edu.au/research/defence/arptn/

Produced by Roman Balla for Digital Sciences Initiative, email: r.balla@bigpond.com