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TNO report

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Technology Watch: International Benchmarking Survey Non-NATO & Non-EU Countries (RVO)

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Executive Management Summary

Background
In 2020 TNO conducted a technology watch and assessment for the Strategic Knowledge and Innovation Agenda 2021-2025 (SKIA) of the Ministry of Defence. Fifteen technology areas were identified, which all have a broad relevance for military use and might potentially lead to disruptive effects in the security and defence domain. The impact and relevance of technology areas is assessed both from an opportunity and a threat perspective. For this technology watch and assessment, a benchmark was performed with Western countries, which generally are like-minded countries, with which the Netherlands already collaborates within the NATO and/or EU frameworks.

The fifteen SKIA technology areas that were assessed, are listed in the table below.[1]

Artificial Intelligence	Weapons	Human Performance & Training
Cyber & Electromagnetic activities	Space	Robotics & Autonomous Systems (RAS)
Quantum	3D printing & Materials	ICT & Networks
Sensor	Biotechnology	Behavioural Engineering
Man Machine Integration (MMI)	Simulation & Virtualisation	Energy

As a result, there is a considerable chance that the armed forces of these countries work with similar technological applications or at least have the same developments in mind. Therefore, TNO has been requested by the Ministry of Defence to examine which technologies relevant for defence are prioritised by non-aligned countries. Non-aligned countries, in this case, are countries which are neither a member of NATO nor the EU.

Selected countries and methodology

Out of 30 potentially interesting countries, four final countries were selected: India, Israel, Russia and South Korea.

Criteria that were used for this selection include geographical and cultural differences (compared to the EU as well as between them), substantial defence budgets, geo-economic power and quality of the academic and industrial base.

For the benchmark we used an existing benchmark methodology, which we adapted to a light version. The key questions we addressed are:

1. To what degree do the four selected referent countries invest and innovate in the fifteen SKIA technology areas?
2. How much priority does each referent country individually give to each technology area?

[1] See Appendix 11.1 for an explanation of each technology area.

3 If this is mutually compared between the four countries, what stands out? Are there for example technology areas that receive an above or below average amount of attention in multiple countries?
4 Are there (sub)technology areas other than the fifteen highlighted SKIA areas in which (one or more of) the referent countries have an interest?

An essential part of this methodology is the collection of data. Since we could not use existing networks through EU and/or NATO collaboration agreements, we needed to base our benchmarking on open sources, varying from official government documents and websites to reports and publications by (inter)national thinktanks and media articles. The open source information that was retrieved for the selected countries proved to be sufficient to conduct the benchmark exercise. Nevertheless, we encountered some difficulties as many official documents were only available in the local languages. There were also differences in the quality and level of detail of the sources between countries and also between technology areas. In general, for both Israel and Russia the amount and in-depthness of the information was richer than for India and South Korea. This is probably due to the fact that Israel and Russia get more attention internationally and thus more sources are available and translated in English.

The timeframe of our technology focus was between now and 15 years in the future, which implies that we looked for technology plans and ambitions which could be realised by 2035. However, most of the retrieved information related to capability investments and plans focusses on the short term (within 5 years). Technology and innovation ambitions on the longer term were often described in rather general terms. Therefore it was difficult to determine investment priorities for the longer term (2030-2035) and as a result, we could not use quantitative data (investments in money) but we had to shift to more qualitative data / judgements in terms of policy, ambitions and focus descriptions related to the technologies.

Technology takeaways

By using scores for each technology area, we assessed if a country is investing (as stated before, we predominantly had to base that on qualitative data) less or more in this technology area than in the other technology areas. In the figure below an overview of these scores is presented, indicating how much priority each technology area receives per benchmark country. A score of 1 implies very low priority, while a score of 5 implies very high priority.[2]

[2] Be aware that the scores represent relative values within a single country. E.g. a 5 score for Israel does NOT imply that Israel spends more money than Russia on AI (Russia getting a 4 score), but it implies that AI is one of the top priorities in Israel while in Russia AI is important but is a lesser priority than Space and Weapons.

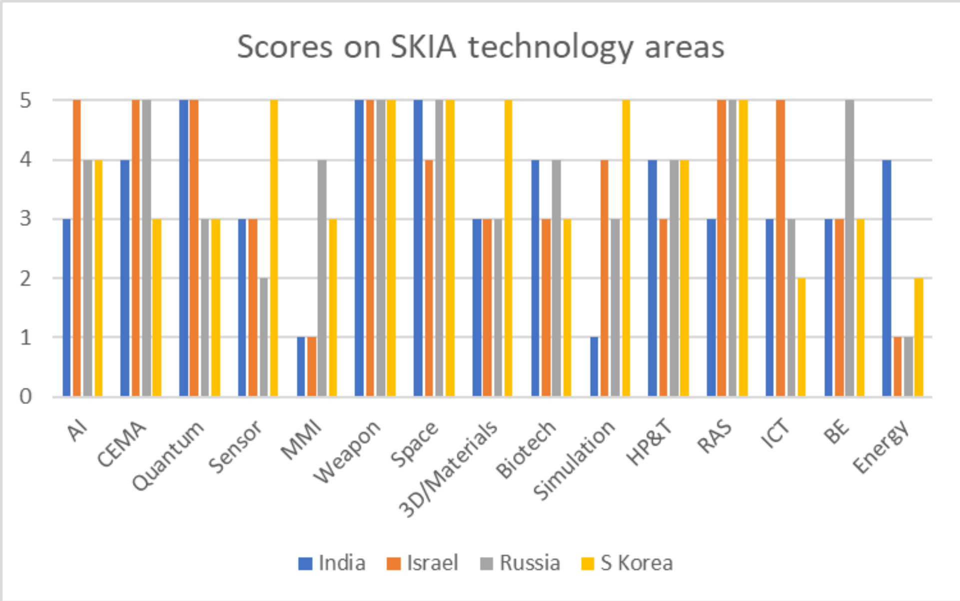

Figure 1 Total benchmark scores.

For these scores we conclude that:

- All 15 SKIA technology areas are given moderate to high attention by at least two of the benchmark countries (with the exception of Energy, even though it is quite highly prioritised by India), which leads to the conclusion that these 15 areas are a firm and well substantiated choice.
- Weapon, Space and RAS are technology areas that get a high priority in most countries. CEMA and Quantum are highly prioritised in two out of four countries, and moderate to high by the rest. Also, AI scores relatively high, with only India giving it moderate attention. This is not a big surprise since these technology areas are generally considered to be the most disruptive ones.
- Man-Machine Integration and Energy score relatively low. The low score on Energy can be explained by the fact that most countries do not consider this as a high military priority yet, as most of the investments go to ‘hard’ technologies like weapons and platforms/systems. The low score on MMI is more difficult to clarify when compared to the high scoring technology areas AI and RAS. The only explanation we can offer is that MMI innovations are often indirectly included in AI and RAS plans.
- Behavioural Engineering (BE) scores average for all countries except for Russia where it has gotten a high score. The reason is most information that was found, was focused on influencing (the behaviour of) populations via for example social media. The use of psychological operations developments within the military context are difficult to gather via open source information. However, since we can safely assume that at least to some degree investments are being made in this domain, all countries were given medium scores. Russia on the other hand has gotten a lot of public attention for amongst others its ‘Maskirovka’ efforts. Based on that information, it can be concluded that this country gives BE a high priority compared to other technology areas.

For each country we have summarised the most interesting findings and takeaways with regard to policies, plans, investments, innovation approaches and activities in the table below.

Country	**Most striking takeaways**
India	• On AI and Cyber there are a lot of policy initiatives but the speed and strength of the Ministry of Defence's (MoD) innovation in AI and Cyber is lacking, making investments currently less effective. • Investments in quantum technologies, hypersonic weapons, directed energy weapons and space technology are considerable and puts India in the global chasing group after the US and China. • Geographical and environmental challenging conditions stimulate India to invest in science and technologies that improve or sustain performance and health care of the military.
Israel	• The Israelian Defence Forces have, probably more than other forces, expanded unconventional capacities and cyber and intelligence capacities, due to constant terrorism threats. • Israel is investing a lot in education, both in the civil and military sector, with a focus on amongst others cyber, biotech and fintech. The aim is to let the IDF benefit from it. • The Mossad's Technological Innovation Fund, focuses on two technology areas outside the SKIA technology scope: Financial Technology (Fintech) and Smart City Tech.
Russia	• Russia aims to close capability gaps vis-à-vis its strategic rivals through a combination of buying new systems and upgrading old ones, especially in relation to its artillery and manoeuvre forces. • The MoD wants the defence industry to convert 30% of its output to civilian and dual-use products by 2025, and 50% by 2030. • High focus on C2 Disorganisation (C2D), on creating a heavily CEMA-denied environment in combat operations, on Anti-Satellite weapons and on behavioural engineering, including using AI-enabled technology. • The Centre for the Fourth Industrial Revolution in Russia focuses, amongst many SKIA technology areas, also on one technology area unknown to the SKIA: Smart City Tech.
South Korea	• Due to scarcity of personnel the military force has to transform in a smaller but more intelligent-based force, therefore prioritising AI, autonomous systems and simulation technologies. • Due to the proxy threat of a North Korean rocket and missile attack, the MoD invests substantially in capabilities that improve the sensor-to-shooter chain (e.g. sensors, interceptors, C4I[3]). • Interesting 'niches' in which the MoD invests include the utilisation of big data for improving military safety and health and the improvement of mental and spiritual abilities.

[3] command, control, communications, computers, and intelligence

Newly identified technologies and innovations

Some technologies were identified that are not fully addressed by the SKIA Technology Watch. Although these technologies relate to one or more SKIA technology areas, they still require additional attention and further analysis, since they are 'odd ones'. These newly identified (sub)technologies are listed below.

(Sub)technology / innovation	Description and military value[4]
Fintech (Financial Technology)	Fintech could be used for military purposes. One example includes blockchain, which can prevent armed forces and their countries from cyber-attacks, defend critical weapon systems, manage automated systems, validate orders and information on the battlefield or manage supply chains and logistics.
Smart City	Smart City technologies include predominantly ICT and sensor technologies like IoT[5], smart and ubiquitous sensors. These are relevant for the defence domain, since a great deal of future warfare will be focused on the networked urban environment.
Atomic	Using the quantised internal energy levels of atoms, Atomic Technology is able to accurately measure physical quantities of objects. Atomic Technology enables long-term quantum navigations under GPS-free or denied environments.
Terahertz	The electromagnetic spectrum in the frequency range between 100 GHz and 10 THz is referred to as terahertz range. By using this spectrum it is possible to realise high-speed/high-capacity communication and to provide all-weather surveillance.
Photonic radar	Photonic radar is a technique/technology by which radar may be produced and analysed with the help of photonics rather than traditional radio frequency (RF) engineering techniques. The frequency of the radar is still in the RF, but lasers are used to create and analyse the RF signals with high precision. It intends to reinforce capabilities to detect multiple threats with precision which are becoming smaller in size and stealthier.
Biomaterial infused invisibility cloaks	Biobased material that bends light to make people and objects nearly invisible to the naked eye. Unlike traditional camouflage materials, which are limited to specific conditions such as forests or deserts, these invisibility cloak intend to work in any environment or season, at any time of day.
Underground (border) sensors	Sensors that collect both acoustic and seismic data, e.g. to detect subterranean tunnels or tunnel activities. The trend is that these sensors are wireless and are part of an interconnected network.
Anti-satellite weapons (ASAT)	Space weapons designed to incapacitate or destroy satellites for strategic or tactical purposes. ASAT roles include: defensive measures against an adversary's space-based and nuclear weapons, a force multiplier for a nuclear first strike, a countermeasure against an adversary's anti-ballistic missile defence.

Innovation culture and approach

A few observations with regards to problems and solutions in innovation approaches were made which are interesting to the Netherlands as well:

- India, Russia and South Korea report a shortcoming of well-trained scientists and engineers in the high-tech domain. The South Korean Ministry of National Defence (MND) claims that it can cope with it by transforming the military into a high-tech force and recruiting and/or engaging more civilian specialists.
- Israel has an enormous innovative capacity. When looking at this country for inspiration, the solution lies in connecting the military to the civilian industry.

[4] The military value has been assessed based on the information provided in the open sources that mentioned these technologies.
[5] Internet of Things

Apart from Israel's specific context where every citizen has a military background, the country also invests a lot in education. This includes universities in general as well as offering educational opportunities within several MoD branches for applicants to be trained in the field of cyber. Also, investments are made in veterans to be schooled in e.g., cyber, biotech or fintech to continue with relevant innovative work that would benefit the MoD. Increased civil-military cooperation makes the process of innovation more efficient and effective.

- All four countries have, although slightly differently organised, several innovation technology centres, where people with different specialist backgrounds as well as different industries come together to research and develop new technologies. This also fosters more civil-military cooperation (albeit there is enough budget and specialists available).

Recommendations
Since we did not have access to classified information and we only used English written documents, we need to be careful in drawing firm conclusions and identifying follow-up actions. However, some recommendations are applicable:

- Executing a benchmark of technology priorities for non-allied countries, operating in different geopolitical and threat environments, is valuable. It prevents tunnel vision and challenges to look for new opportunities and insights. Actively working on and maintaining databases of relevant sources related to global technology and innovation developments would smoothen and ease future benchmarking, and probably make it more cost-effective. If subject matter experts for specific countries could be linked up to both the process of maintaining a database and the actual benchmarking itself, the quality of the results would significantly improve.
- Although all 15 SKIA technology areas are well covered by one or more benchmark nations, some technologies and/or innovations within these technology areas (or related to these) draw additional attention. Either because these get a rather high appraisal, more than one might expect, or because these are not yet covered within the TNO Innovation Radar. The most striking ones are already addressed in one of the previous sections (*see newly identified technologies*). It is recommended to conduct more research on these areas, preferably combined with a brief impact assessment. An easy way to do so is to incorporate these technologies in the Innovation Radar, not yet as a substantial technology area but probably clustered with a few innovations that can be temporarily linked to one of the 15 existing technology areas.

Contents

1 Introduction

1.1 Background

Since 2014, TNO has been conducting ongoing technology watches for the Dutch Ministry of Defence. In 2018, the TNO Innovation Radar was developed and has been used for this purpose since then. An important part of the Innovation Radar is assessing the military relevance and impact of innovations. The Innovation Radar is filled and maintained by approximately 40 experts from TNO and MARIN. These experts make use of knowledge and insights obtained in research programmes and literature, but also through national and international networks in which the experts are active (universities, NATO STO, EDA, bilateral partnerships).

Last year (2020), TNO conducted a technology watch and assessment for the Strategic Knowledge and Innovation Agenda 2021-2025 (SKIA) of the Ministry of Defence. Fifteen technology areas[6] were identified, which all have a broad relevance for military use and might potentially lead to disruptive effects in the security and defence domain. The impact and relevance of technology areas is assessed both from an opportunity and a threat perspective. For this technology watch and assessment, a benchmark[7] was performed with Western countries, which are mostly like-minded countries, with which the Netherlands already collaborates within the NATO and/or EU framework. As a result, there is a considerable chance that the armed forces of these countries work with similar technological applications or at least have the same developments in mind.

In order to see whether this international benchmark can be supplemented with new knowledge, the Ministry of Defence, in particular the department of Strategy and Knowledge within the Policy Directorate, requested TNO to examine what non-aligned countries are doing with regard to technology developments relevant to defence. Non-aligned countries, in this case, are countries which are neither member of NATO nor EU. In addition, our main interest is in countries that are geographically located in other regions (e.g. not in Europe) and therefore face different threats and geopolitical interests. By looking at these types of countries, unexpected views and outcomes might be found that can be used to supplement and possibly complement the technology watch and assessment carried out for the SKIA.

1.2 Study objective

The aim of the project is to test the fifteen technology areas that have already been identified for the SKIA, by exploring technology developments in non-NATO and non-EU countries. For that purpose we selected a limited number of interesting and relevant non-NATO and non-EU countries, which we address as *benchmark countries* in this report.

[6] In Appendix 11.1 the fifteen technology areas are listed including a short description.
[7] The term 'benchmark' is interpreted broadly for this study. It is defined as a point of reference against which cases can be compared. The point of reference in this study are the fifteen technologies areas that were identified in the SKIA. They are used as a standard to see to what extent other countries are investing in the same technology areas.

Benchmark countries need to meet criteria like defence expenditure, geopolitical power and innovation strength, otherwise a country is not a real relevant player in the global defence domain, and will therefore likely not be investing in emerging and disruptive technologies. By comparing each benchmark country against the fifteen SKIA technologies we were able to determine whether the benchmark countries have the same military interest in these technology areas. In case we identified differences, we tried to find out what the main drivers for these differences were. Differences can be either new technology areas other than the fifteen SKIA ones or SKIA technology areas that are not of interest to one or more benchmark countries. In case of new (sub)technology areas, this might lead to the conclusion that we will have to monitor these ones in the years to come.

The main aim of this project is to gain new insights, and not to advise the Ministry of Defence to make specific changes to their current technology and innovation policy on the basis of this research. In short, the SKIA 2021-2025 and the underlying 2020 Defence Technology Watch 2020 remain in force. Certain new insights could, however, lead to additional emphases within the ongoing TNO technology watches and assessments.

1.3 Study approach

Based on a literature scan, a longlist of interesting and relevant countries was developed, after which we performed a brief mutual comparison in order to select a shortlist of four countries for the in-depth benchmarking (*the benchmark countries*). The down selection to the final four is done due to time and budget constraints. Some reserve countries were identified, which could be used in case one or more of the initial four benchmark countries would provide to less valuable results, for example due to lack of relevant data and information.

For the benchmark we used an existing benchmark methodology, which we adapted to a light version. An essential part of this methodology is the collection of data and information. Since we could not use existing networks through EU and/or NATO collaboration agreements, we needed to base our benchmarking on open sources, varying from official government documents and websites to reports and publications by national and international thinktanks and media releases and reports. The timeframe of our technology focus was between now and 15 years, which implies that we looked for technology plans and ambitions which could be realised before approximately 2035.

In order to systematically categorise the results regarding the fifteen SKIA technology area as well as to simplify the mutual comparison between the benchmark countries, we developed a template summarising the key findings for each country and indicating to what degree a country invests in each of the fifteen SKIA technology areas.

2 Benchmark methodology

2.1 Objective and necessity

A benchmark methodology is needed to ensure that all countries are examined in an unambiguous and corresponding manner and that the objective of examination can be assessed against a given benchmark. In our study the benchmark is provided by the fifteen SKIA technology areas. That means that we examined to what degree the four selected benchmark countries invest and innovate in these technology areas. In addition, we looked for:

- SKIA technology areas that are not relevant to one or more of the benchmark countries, and
- (Sub)technology areas other than the areas highlighted in the SKIA in which one or more of the benchmark countries invest and innovate.

Moreover, we examined all technology areas more in depth, by looking specifically for types of innovations that are of interest to or even implemented by the benchmark countries. By doing so we were able to identify whether the current SKIA technology areas should be complemented by new findings, like for example a certain technological trend or a method to innovate.

The benchmark study culminated in visual metrics that reflect the level of prioritisation that the referent countries give to each technology area.

2.2 Methodology benchmark *light*

TNO developed a benchmarking methodology (de Spiegeleire, 2006), whereby the US Army's official definition of benchmarking was adopted as: "a systematic process of comparing, measuring, and analysing the products, services, or processes of an organisation against current best practises of other (preferably world-class organisations in order to attain superior performance" (US Army, 1997). The four main steps in the benchmarking methodology are visualised in orange, see figure below.

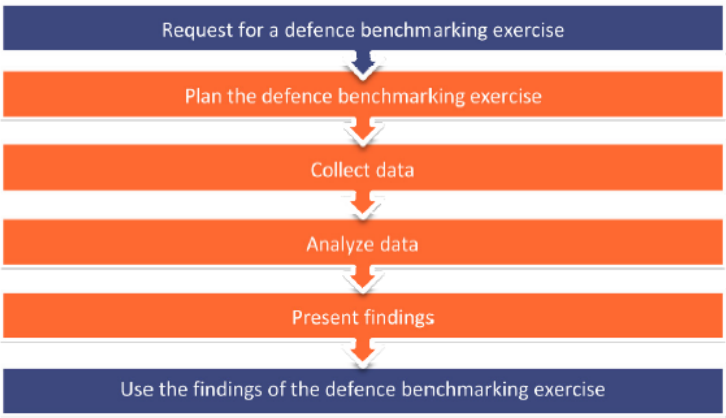

Figure 2 The stages of a generic benchmarking exercise (de Spiegeleire, 2006).

Due to time and the scope of this project, a *light* version of the TNO benchmarking steps has been carried out. The four main steps are used as a baseline and for each main step some sub-steps have been identified. A summary of the key (sub-) steps is provided below.[8]

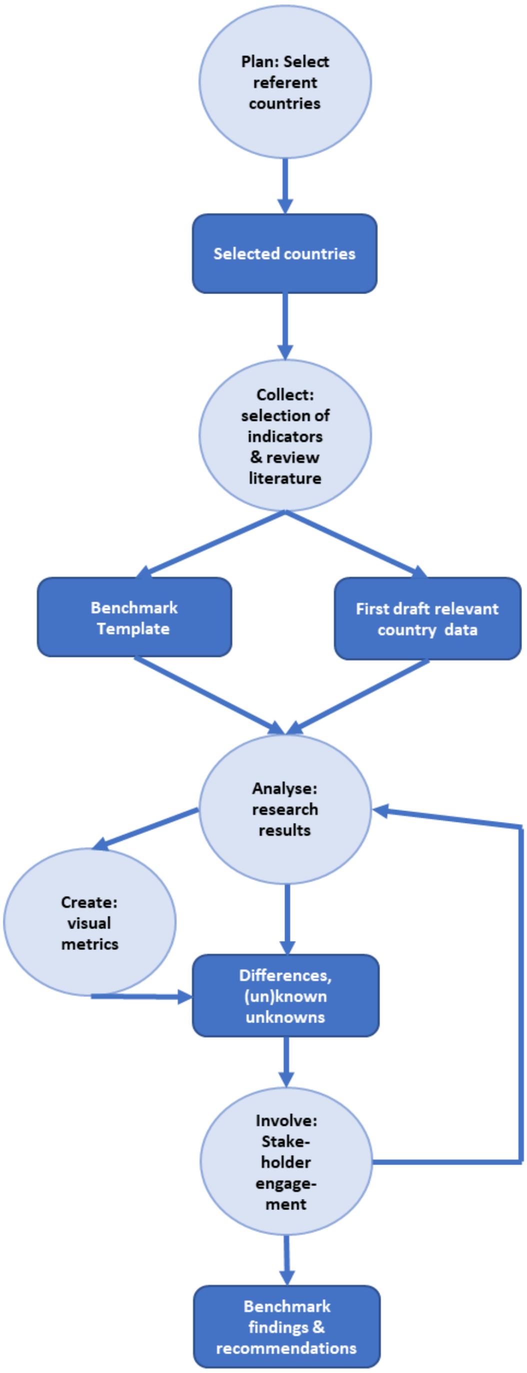

Figure 3 The benchmark methodology light.

1 Plan the benchmarking exercise
First, categories are identified within the benchmarking topic that can be operationalised and thus systematically measured. In our study these categories constitute the fifteen SKIA technology areas. The second step is identifying referents, in our study reflecting the non-NATO and non-EU countries that are sufficiently interesting and relevant with respect to military technology developments. A number of criteria have been chosen to support the country selection (e.g. size or ambition level of the country).

2 Country selection: longlist, shortlist and final
We started with a longlist of countries that do not have NATO nor EU memberships, but do have global or regional power, which is based on a combination of political, economic and military power. Based on a quick scan, a shortlist is formed, which then filters down into a final list of four referent countries and three back-up countries. The amount of countries is based on pragmatic reasons, namely budgetary and time limitations of the project.

The selection of countries for the longlist, shortlist and the final list is based on criteria which are derived from a literature scan on (defence) technology and innovation benchmarking.[9]

3 Benchmark template
To ease the systematic collection and processing of country specific information, a template is developed and applied. The template consists of data concerning the military technology and innovation landscape of a country and is inspired by the literature scan. It includes the size of the armed forces, defence investment budgets, high reputation facilities and well known arms industries.

Next to that, it lists all fifteen SKIA technology areas. By using indicators (-, 0, +) we assessed if a country is investing and focussing in this technology area less

[8] For more detailed descriptions of the TNO benchmarking methodology, see: (de Spiegeleire, 2006) and (de Spiegeleire & Jadoul, 2007).
[9] Chapter 3 provides more detailed information regarding the selection process, including the criteria used.

or more than in the other technology areas. The assessment is based on how we perceived the qualitative and quantitative data retrieved from the open sources. Note that the assessment reflects an internal comparison, as it is assessed how much priority a referent country gives to each technology area that is being benchmarked. This could for example lead to the observation that that country relatively invests and innovates a lot in AI as compared to biotechnology.

4 Literature review / data collection
After the selection of referents (countries), a systematic literature scan based on open source information has been carried out to collect data for the benchmark and for filling in the templates. This included preferably formal policy documents and military strategies. Also reviews and analyses by (academic) experts and think tanks as well as media sources are used, provided that the quality and reputation of the source is warranted. After scanning all available and relevant sources we decided whether we got sufficient data to do the benchmark. If not, then back-up countries on the reserve list would come into the picture.

5 Data analysis
In this step of the process it is important to think about how the differences between the selected indicators of the countries can be measured. If the indicators are measurable and comparable (e.g. military expenditure in relation to GDP), it is easier to normalise the metrics (meaning that they are expressed in common units). Numerical data can then be useful. In this project we look at whether the 15 SKIA technology areas are given substantial attention in the benchmark countries. Therefore we did use qualitative data to express and explain what topics are addressed within the specific technology areas. Also we explained why the referent countries have specific interests in particular technology areas. To provide quick and easy overviews we used a simple metric to indicate high and low focus in technology areas (relatively to each other) by a referent country.

6 Stakeholder engagement
Once we completed the literature analysis, a first draft of the template and initial takeaways were reviewed by country experts, such as Dutch national representatives in those countries (e.g. DEFAT) and people working at NL MoD's International Military Staff. The additional information provided is then used to complement the country template and improve the research paper.

7 Benchmark findings and recommendations
Finally, we assessed the major findings, with a special interest in the following issues and questions:
- To what degree do the four selected referent countries invest and innovate in the fifteen SKIA technology areas?
- How much priority does each referent country individually give to each technology area?
- If this is mutually compared between the four countries, what stands out? Are there for example technology areas that receive an above or below average amount of attention in multiple countries?
- Moreover, how does this compare to the Netherlands?
- Are there (sub)technology areas other than the fifteen highlighted SKIA areas in which (one or more of) the referent countries have an interest?

8 Visualisation and presentation

Based on the analysis and its outcomes, quantitative metrics were created to visualise the findings.[10] In this stage an appropriate metric is developed for a certain category (one of the SKIA technology areas), after which the referent countries are positioned along that metric. One example is to position the countries in terms of how much priority each one gives to a certain technology area. The advantage of such visualisation is that it provides the reader with (albeit simplified) conclusions of the research at a glance. It demonstrates the benchmark: e.g. where does each referent stand in relation to the others?

[10] So-called 'topic-to-metric decomposition'.

3 Selection benchmark countries

3.1 Selection process

The figure below depicts the various steps that have led to the final selection of 4 referent countries, referred to as the *benchmark countries*. Each of these steps is explained in more detail in the following sections.

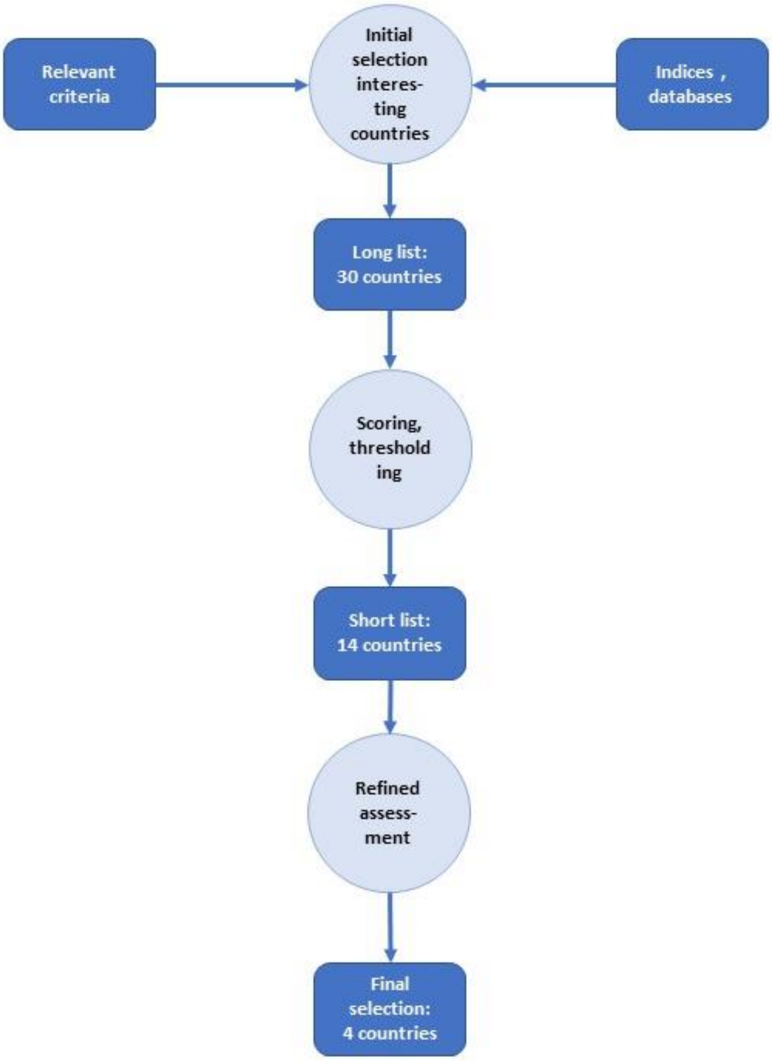

Figure 4 Final selection process benchmark countries.

3.2 Relevant criteria

In order to select our final four benchmark countries, five core criteria were created. These criteria were made based on the literature scan on (defence) technology and innovation benchmarking (Freeman, J.; Hellgren, T.; Mastroeni, M.; Paoli, G.P.; Robertson, K.; Black, J., 2015) (European Defence Agency, 2006) (Ministry of Economic and Business Affairs & Centre for Economic and Business Research, 2004). The criteria are:

- *Geographical and cultural differences*
  The countries selected are not members of the EU and NATO frameworks. Therefore the main focus is directed to countries from outside Europe and North America.[11] Also, it is important that there are sufficient geographical differences between the selected countries, since this likely leads to different challenges and threats (or threat perceptions) and therefore possible different technology priorities.
- *Defence budgets*
  We looked for countries that have serious ambitions in developing and maintaining an innovative military force. This requires substantial defence budgets and military expenditures to back up the ambitions.
- *Global or regional geoeconomics*
  Countries that are keen to obtain a privileged or dominant economical position in the world or in the region, do undoubtedly strive for sufficient military power. Therefore they need to keep up with the modernisation of their armed forces. To get ahead of their global or regional competitors, they are sagacious to find and implement technologies by which they can make a difference.[12] That makes them interesting benchmark countries.
- *High-quality academic landscape*
  Countries in which the academia flourish and are high-ranked globally or regionally, have a strong base for research and technology development. The military might profit from it, which can spur innovations that are less common and/or widely spread.
- *Industrial base*
  Countries that have a strong national industry, especially in technology areas that are relevant for the military (arms industry or industries that develop dual-use technologies), are well placed to modernise their armed forces and provide them with highly advanced materiel. This could lead to niche capabilities and innovations, with a chance that they will not be exported due to national restrictions.

[11] Belarus, Bosnia and Herzegovina, Moldova, Russia, Serbia, Switzerland and Ukraine are the seven European countries without a NATO and/or EU membership.
[12] If historical experience holds true, economic growth in some of the present-day candidates for great-power status will spur them to increase the growth rate of their military expenditures and, as a result, their military capabilities. But each country is unique, and strong economic growth need not imply a commensurate expansion of military spending or capability. History suggests that perceived threats from abroad may be the most important factor leading potential great powers to increase military expenditures. This distinction is important, because policies designed to deter foreign military expansions motivated by ambition may have perverse effects if the expansions are in fact motivated by fear. This analysis suggests that today's large and fast-growing economies are most likely to devote a growing share of their government and national resources to military expenditures when the external environment appears highly unstable. During such times, an increase in the size and effectiveness of these states' armed forces can lead to a significant reconfiguration of the global balance of power. See also: (Castillo, Lowell, Tellis, Munoz, & Zycher, 2001).

3.3 Data collection

For the initial selection of interesting benchmark countries (*the longlist*) we collected relevant and reliable data to assess the aforementioned criteria. We used several global indices and databases that are well known and that use high standards for their data collection and analysis. Four indices and databases were selected which cover the set of criteria:

- *Global Fire Power (GFP) Index* (Global Firepower, 2006)
  Since 2006 the GFP scores and ranks 140 modern military powers based on each nation's potential and conventional war-making capabilities. The criteria used relate to manpower, equipment, budgets and investments, natural resources and geography. The GPF is a US based platform and website. The GPF index is useful to rank and compare countries on at least three core criteria: *Geographical differences*, *Defence budgets* and *Global or regional geoeconomics*.
- *SIPRI Military Expenditure and Arms Industry databases* (SIPRI, sd)
  SIPRI is an independent international institute, based in Stockholm. It is dedicated to research about conflict, armaments, arms control and disarmament. Established in 1966, SIPRI provides data, analyses and recommendations, based on open sources, to policymakers, researchers, media and the interested public (McGann, 2021). Amongst the many databases offered by SIPRI the databases on Military Expenditure and Arms Industry (presenting the top-100 arms-producing and military services companies in the world excluding China) are the most relevant for selecting countries based on two defined criteria: *Defence budgets* and *Industrial base*.
- *QS World University Rankings* (Quacquarelli Symonds, 2004)
  The QS World University Rankings portfolio, inaugurated in 2004, is provided by Quacquarelli Symonds, which offers services, analytics, and insights to the global higher education sector. QS World University Rankings has grown to become the one the most used sources of comparative data about university performance and will thus be used to compare the benchmark countries based on the criterium: *high-quality academic landscape*.

3.4 The longlist

For each region we selected a number of non-allied countries that score best on the GFP index. In addition, we collected information on the other criteria, using the indices and databases mentioned above. This resulted in a set of 30 countries (*the longlist*) potentially being interesting for the benchmark study. In the table below an overview of these countries and their scorings is provided.

Country	GFP index[13]	SIPRI Military Expenditure[14]	SIPRI Arms Industry[15]	QS world universities[16]
	Global/ regional geoeconomics	*Defence budgets/ % of GDP*	*Industrial base*	*Academic landscape*
Africa				
North Africa				
Algeria	27	9,7 bn / 6,7%	0	0
Sub-Saharan Africa				
Nigeria	35	2,5 bn / 0,6%	0	0
South Africa	32	3,1 bn / 1,1%	0	7
America				
Central America				
Mexico	46	6,1 bn / 0,6%	0	12
South America				
Argentina	42	2,9 bn / 0,8%	0	13
Brazil	9	19,7 bn / 1,4%	0	14
Colombia	39	9,2 bn / 3,4%	0	11
Venezuela	43	2,1 bn / 2,3%	0	4
Asia				
East Asia				
China	3	252,3 bn / 1,7%	N/A[17]	51 (3 in top 50)
Japan	5	49,1 bn / 1,0%	6 (2 in top-50)	41 (2 in top 50)
North Korea	28	No data	0	0
South Korea	6	45,7 bn / 2,8%	3 (1 in top-50)	29 (2 in top 50)
Taiwan	22	12,1 bn / 1,9%	0	16
South Asia				
Bangladesh	45	4,6 bn / 1,3%	0	2
India	4	72,8 bn / 2,9%	3 (1 in top-50)	21
Pakistan	10	10,3 bn / 4,0%	0	7
South-East Asia				
Indonesia	16	9,3 bn / 0,9%	0	8
Malaysia	44	3,8 bn / 1,1%	0	20
Myanmar	38	2,4 bn / 2,9%[18]	0	0
Singapore	40	10,9 bn / 3,2%	1	3 (2 in top 50)
Thailand	26	7,3 bn / 1,5%	0	8
Vietnam	24	No data	0	2
Oceania				
Australia	19	27,5 bn / 2,1%	1	36 (3 in top 50)
Middle East[19]				
Egypt	13	4,5 bn / 1,2%	0	4
Iran	14	15,8 bn / 2,2%	0	5
Israel	20	21,7 bn / 5,6%	3 (all in top-50)	7
Saudi Arabia	17	57,5 bn / 8,4%	0	10
UAE	36	22,7 bn / 5,6%	0	8
Europe non-EU/NATO				
Russia	2	61,7 bn / 4,3%	10 (3 in top-20)	28
Ukraine	25	5,9 bn / 4,1%	1	6
Reference				
Netherlands	37	12,5 bn / 1,4%	0	13

[13] The place of countries in the GFP index, from 1 – 140, (Global Firepower, 2021).

Some observations based on the scorings and ratings:

- Most of the highest scoring countries are Asian countries. Especially China, India, Japan and South Korea have high GFP scores, substantial military expenditures as well as more than 20 top-1000 universities. This makes them highly relevant and interesting countries for the benchmark.
- As can be expected, Australia is the only relevant military player in Oceania, and scores reasonably well compared to the other countries worldwide.
- Data concerning the defence budgets of North-Korea and Vietnam is lacking, making them difficult to incorporate in the benchmark.
- Among the listed Middle Eastern countries there is no country that outperforms the others on all criteria. Although Egypt has a far lower military expenditure than the others, it gets the highest GFP rating. Saudi Arabia spends the highest share of its GDP on defence (8,4%). Israel scores reasonably well on all criteria, with a remarkable high ranking in the global arms industry base.
- African countries score quite low on this list. However, Algeria spends the second highest share of its GDP on defence (6,7%). Although South Africa does not have a company in the top 100 of global arms industry companies, most of its (civil) technology companies do perform quite well.
- The South and Central American countries are lagging behind compared to the other listed countries, with the exception of Brazil.
- China, India, Japan, Russia, South Korea, and to a lesser extent Australia and Israel are amongst the top-20 of the GFP index and do get (high) scores on all three other criteria.
- A lot of listed countries do not have any companies in the list of top-100 arms-producing and military services companies. Nevertheless, some of these countries do get high rankings in the GFP, like Brazil (9), Pakistan (10), Egypt (13), Iran (14), Indonesia (16) and Saudi Arabia (17), and are therefore still relevant and interesting to be selected as benchmark countries.

3.5 The shortlist

To reduce the 30 countries on the longlist we added some weighting factors and thresholds to the criteria. We used the ranking in the GFP index and the scores on the academic landscape as the primary criteria, and the defence budgets (which are implicitly considered in the GFP index) and the industrial base as secondary criteria. The latter proved to be less discriminating since only few countries had military arms sale industries in the top-100.

Quantitatively this comes down to:

- Being ranked in the GFP top-20 index, and
- Getting a reasonable score on the academic landscape (at least 3 universities in top-1000).
- Minimum of either 1.0 % of GDP or 4 bn dollars on annual military expenditure.

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[14] Represents military expenditure in 2020 in bn US dollars / share of GDP in %.
[15] Represents the number of top-100 arms-producing and military services companies in the world excluding China. The database is lastly updated in 2018.
[16] Represents the number of top-1000 best universities in the world.
[17] China's military industrial base is not presented in this database.
[18] Data is featured as 'highly uncertain data'.
[19] The Middle East is generally considered to include the countries on or near the Arabian Peninsula, including Egypt, Iran, Iraq, Saudi Arabia, Yemen, Syria, Jordan, the United Arab Emirates, Israel, Lebanon, Oman, the Palestinian territories, Kuwait, Qatar, and Bahrain.

When applying these criteria we did ended up with the following countries for the shortlist: Brazil, China, Japan, South Korea, India, Pakistan, Indonesia, Australia, Egypt, Iran, Israel, Saudi Arabia and Russia. However, this would imply that no African country is selected, apart from Egypt which is both an African and Middle-Eastern country. For that reason South-Africa is added to the shortlist due to its unique geopolitical position, its industry and academic base (although the figures do not underline this sufficiently). As a result the initial longlist of 30 countries is now reduced to a shortlist of 14 countries.

Based on the shortlist a concise assessment of the pros and cons of each country is performed, using input from open sources. In the overview below the assessment is provided, showing the arguments for each country for either being selected (marked green), being on the reserve list (marked yellow), or being rejected for benchmarking. Apart from the arguments the bottom line for the selection was a maximum of 4 benchmark countries with 2-3 countries on the reserve list.

Country	**Selected / Reserve / Not selected**	**Arguments**
Africa		
South Africa (Sub-Saharan Africa)	Not selected	During the Apartheid South Africa was forced to be self-reliant. Its national defence industry flourished and state-of-the art equipment and systems were produced. But in the 90s the armed forces became increasingly drawn into peacekeeping and internal roles, such as fighting crime. Defence budgets have dropped from 4% to almost 1% of the GDP (Heinecken, 2020). As a result, the armed forces have not (yet) made the transition into the 21st century in terms of how to combat future threats, and the use of technology as a force enabler and multiplier. We therefore do not expect to find surprising and new technologies and innovations.
America		
Brazil (South America)	Reserve	Brazil would be the only South American country that might be interesting for the benchmark. Currently, Brazil seems to be relying on military knowhow and technology from abroad, in particular the US considering some recent cooperation agreements that were signed (Milani, 2019). The Brazilian defence industry is increasing its global position, however still marginally. Due to its high GFP ranking, its more than decent academic landscape and foremost its geographic position, we keep Brazil on the reserve list, mainly as backup for India or Russia (another BRIC country).
Asia		
China (East Asia)	Not selected	Although one of world's leading (military) powers with a significantly modernisation of the armed forces in progress, China is not selected. One could consider China one of the 'usual suspects' since it is a country that many keep a close eye on (including national intelligence services, US, UK).
Japan (East Asia)	Reserve	It is either Japan or South Korea that we would include in the benchmark. Although Japan seems to score higher, it does not have a "military" per se, but more of a "self-defence force." South Korea on the other hand has a fully-fledged military that it can legally deploy abroad. Also, Japan was until recently hampered by the military export ban signed in 1976 and lifted in 2014 (Herman, 2016). It would thus make more sense to choose South Korea to represent East Asia. Nevertheless we keep Japan as a back-up.

Country	**Selected / Reserve / Not selected**	**Arguments**
South Korea (East Asia)	Selected	See arguments mentioned for Japan. In addition, South Korea has been on a path to become a significant arms producer and supplier for 20 years, rising from the 31st ranked arms exporting country in 2000, to number six in 2020, according to SIPRI's arms transfer database. This might imply that South Korean made military materiel is much in demand, demonstrating its high quality. It should be mentioned that NATO identifies South Korea (or the Republic of Korea) as one of its 'partners across the globe' to develop cooperation. (NATO, Partners, 2020)
India (South Asia)	Selected	India seems to be a dark horse. A lot of attention is paid to China and Russia, and India stays out of sight. This could be considered as remarkable as India is 4th on the GFP index and 3th on the military expenditure list. In combination with its strong industrial and academic base, India is worth it to examine more deeply.
Pakistan (South Asia)	Not selected	Pakistan is mainly an arms importer, and has only modest own development capabilities. It's military budget is also relatively small. Since India is much more interesting for the benchmark, and we do not need to select 2 South Asia countries, India is preferred above Pakistan.
Indonesia (South East Asia)	Not selected	Indonesia has the most developed defence industry in South East Asia. However, the development of the defence industry in the region is still relatively new and not yet up to par with the industrial developments in neighbouring East or South Asia (Shiddiqy, Bainus, Sumadinata, & Sudirman, 2019). Therefore, Indonesia is not selected for the benchmark.
Australia (Oceania)	Not selected	Although Australia is not part of the EU, NATO and the North Western hemisphere, it is one of the closest allies of Western countries (e.g. NATO partner for peace nation, AUKUS) and has culturally a strong link and identification with the West. Therefore we do not expect significant differences with technology areas and innovations that are developed in the West, although Australia heavily invests in defence innovation (Australian Government, Department of Defence, 2020).
Middle East		
Egypt (Middle East)	Not selected	Egypt is slowly progressing when it comes to its innovative potential, but is still lagging behind countries like Israel and South Africa. In the military domain the military companies are mostly or to a great extent state-owned. The Egyptian government is characterised by very high bureaucracy, which tempers high expectations of military innovation or technology progress. Therefore we do not select Egypt for the benchmark.
Iran (Middle East)	Not selected	Although Iran has a fairly high place on the GFP list, it is difficult to analyse the real value of its military capabilities since official releases on its great power status have been identified as tools for deception and propaganda. Also, the Iranian defence industry is still limited in meeting the operational needs of its armed forces (Czulda, 2020). It thus remains technologically inferior compared to competing states (Defense Intelligence Agency, 2019). For these reasons Iran is not selected for the benchmark.
Israel (Middle East)	Selected	The Israel Defence Forces are one of world's most experienced forces when it comes to being engaged in war or armed conflict. Their military industrial base is strong and the past has shown that Israel develops impressive innovative military capabilities, like the Iron Dome, a mobile all-weather air defence system. Although Israel is a member of the Mediterranean Dialogue (MD) – a cooperation framework with NATO – this does not give them a separate NATO-status (NATO, Mediterranean Dialogue, 2021). For these reasons Israel is selected to be benchmarked.

Country	Selected / Reserve / Not selected	Arguments
Saudi Arabia (Middle East)	Reserve	Saudi Arabia has one of the highest defence budgets in the world and by far the highest in the Middle East. The country is also one of the largest importers of arms and other military materiel from the US. However, it has been transforming its defence industry during the past years, and aims to localise over 50% of its military equipment by 2030. The government also aims to grow its national holding company for domestic military manufacturing (SAMI) to become one of the top-25 military industrial companies in the world by 2030 (Oxford Business Group, 2021). The foreseen growth makes Saudi Arabia an interesting country for the benchmark. However, one can question how realistic the goal to spend 50% locally is. Therefore, it is put on the reserve list, as a back-up for Israel (Middle East).
Europe non-EU/NATO		
Russia (Europe)	Selected	Partly the same argument as for China applies, being that Russia is already a 'usual suspect' since many others already keep a close eye on Russia. However, there is a significant difference with China. Due to its recent military operational experience and involvement in Syria and Libya the Russian armed forces have included valuable lessons learned in their current modernisation programmes. Even despite Russia's relatively low defence budget (compared to the US, China and EU), new military innovations have already been taken up. Therefore we do think it is worthwhile to have a better look at Russia's technology and innovation developments.

3.6 Final selection

Based on the arguments provided in the table above, it has been decided to select the **following four countries for the benchmark**:
- India (South Asia);
- Israel (Middle East);
- Russia (Europe);
- South Korea (East Asia).

With these four countries we ensure:
- A geographical mix of Asia (East and South), the Middle East and Europe (non-aligned);
- A mix of 2 large states (Russia and India) and 2 small-medium sized states (South Korea and Israel);
- A selection of states that rely heavily on military power since all states face cross-border threats and lifetime geopolitical competitors (South Korea vs North Korea, Russia vs NATO, India vs Pakistan, Israel vs Arab world).

Japan (East Asia), Brazil (South America) and Saudi Arabia (Middle East) were assigned as the reserve countries in case the quality and/or quantity of information retrieved for one or two of the selected countries would be below expectation. Although that did not happen, these 3 countries are still interesting to monitor and assess (probably in a later stage or other project).

4 India

4.1 Overview benchmark results

4.1.1 General data and assessment results

The table below presents key data that reflect India's geopolitical challenges and drivers as well as its strengths and general facts relevant to the defence and security environment.

INDIA: GENERAL INFORMATION	
Geopolitical challenges and drivers	• Conflict with Pakistan • Competition / border conflict with China • Indian Ocean, a zone with great potential for growth in transoceanic commerce but also with intensified competition and rivalry
Strengths	• The world's largest democratic republic • Nuclear weapons • Non-aligned country having good relationships with Russia and parts of Western world • About 50% of population is below the age group of 24, providing a large workforce for many decades
Defence budget [2020]	• $72,8 bn (2,9% of GDP) (SIPRI, sd) • $52 per capita • 9% of total government budget
Defence size [2020]	• 1,44 mln active personnel (Global Firepower, 2021)
Defence R&T[20] budget [2021]	• $1,24 bn annual operating budget (Raghuvanshi, 2021) • $1,55 bn capital expenditure (one-time large purchases of R&T fixed assets) (Raghuvanshi, 2021)
Defence R&T partner countries	• Cooperation agreements with 83 countries (Government of India, Ministry of Science and Technology, 2021) • Most prominent partners: Australia, Canada, France, Germany, Israel, Japan, Russia, United Kingdom, United States
Arms industries	• Hindustan Aeronautics, Indian Ordnance Factories, Bharat Electronics
Arms export [to]	• No significant countries
Arms import [from]	• Russia, France, Israel, United States (SIPRI, sd)

The following table provides a summary of the key findings for each of the 15 SKIA technology areas. The actual (in-depth) benchmark analysis is reported in Section 4.2. The column 'Focus' indicates the level of priority the referent country gives the respective technology area vis-à-vis other technology areas: high (+), moderate (0) or low (-). This reflects the governmental attention, based on policies, plans and investments, as well as concrete activities in research, technology and innovation. Also, it demonstrates the level of technological development that one can expect from a powerful military player.

[20] Research & Technology; some countries use the term Research & Development (R&D).

INDIA: TECHNOLOGY AREAS			
Technology Areas		**Focus (+,0,-)**	**Findings**
1	Artificial Intelligence	0	• Speed and strength in innovation is lacking, despite a lot of policy initiatives. • Automatic speech recognition is one of the key areas as well as autonomous systems, although progress is slow.
2	Cyber & Electromagnetic Activities	0/+	• For cyber modest progress on governmental level; the private sector is moving more quickly. • Military attention for cyber has increased since 2020 (due to China's cyber threat). • Electronic Warfare capabilities are on the rise.
3	Quantum	+	• Massive boost in budget, now time to make transition from theory to infrastructure and capacities. • Aimed at communications, computing, cryptography and materials development
4	Sensor	0	• In all domains and for all sensor types developments are ongoing • No very specific niche developments, more mainstream
5	Man Machine Integration[21]	-	• Digital literacy throughout India varies a lot, which pushes for innovations in easy-to-use man-machine interfaces. • However, very little information found about military applications.
6	Weapons	+	• Hypersonic weapons using scramjet technology. • Directed energy weapons, both laser and high power EM.
7	Space	+	• Full launch capabilities (one of six nations in the world). • Cryogenic rocket engine technology to carry heavy satellites.
8	3D printing & Materials	0	• 3D printing is seen as very valuable, but real progress has still to be made. • Long term objective is to evaluate key biological effects of nanomaterials.
9	Biotechnology	0/+	• Biomaterial infused invisibility cloaks. • Much focus on biotech research to mitigate problems like contaminated drinking water, diseases and insects and snakes bites.
10	Simulation & virtualisation	-	• Growing gaming industry and human capital is an opportunity for the MoD • However, the military innovation currently lags behind, despite (not very sharply described) polices and plans to invest more in simulators for military training.
11	Human Performance & Training	0/+	• Focus on high altitude and extreme (hot, dry, wet swamp) climate operations. • Focus and progress on using Yoga to improve performance (cognitive, mental).
12	Robotics & Autonomous systems	0	• Catching up in robotics, mostly pre-programmed due to slow pace in AI • Swarming: demonstration of swarm attack by drones on multiple targets.
13	ICT & networks	0	• Difficult to assess since there is only very few dedicated information on military ICT/C2. • Most developments are very common, like BMS, security, cloud computing, data analytics
14	Behavioural engineering	0	• Information warfare branch to counter the exponential use of disinformation, also against MoD. • No evidence that psychosocial science engineering is used for active influencing operations by the military.
15	Energy	0/+	• Already developing technologies like fuel cell technology and conversion of biomass to bio-energy and biofuels • Military might profit from India's predicted future as one of the global leaders in solar power and battery storage

4.1.2 Takeaway's

The key takeaway's for the assessment of India's ambitions and activities on military science and technology are:

- Speed and strength in innovation in AI and cyber is lacking, despite a lot of policy initiatives at the MoD level. This is rather disappointing considering the strength of India's military force and its defence budgets. However, the industrial sector is more pro-active in these areas, but not much spin in to the military force has achieved so far, despite the many initiatives to foster public-private cooperation.
- Investments in quantum technologies, hypersonic weapons, directed energy weapons and space technology appear to be quite successful. In those areas India seems to be part of the chasing group after US and China.
- Geographical and environmental challenging conditions stimulate India to invest in science and technologies that improve or sustain human performance, e.g. military performance at high altitude and extreme hot weather conditions, and in areas with disease vectors and contaminated drinking water.
- Threats related to disinformation, drones and border security steer innovation towards countermeasures against these threats. Jamming and laser solutions to neutralise drones, the set-up of an Information Warfare branch working on new techniques and tools to counter disinformation are leading examples in this context.

4.2 Benchmark analysis

This subchapter presents the actual benchmark analysis upon which the table above and the key takeaway's are based. It starts with an introduction, after which it zooms in on India's research, technology and development base in general. Following, it analyses each technology area more in-depth. It ends with a concise table with the most important official sources used.

4.2.1 Introduction

With over 1.4 mln active personnel, India has the world's second-largest military force and has the world's largest volunteer army. Since its independence in 1947, India been involved in several military conflicts. After a friendly relationship with China, India went to war with China in 1962, and lost disputed territorial areas to China. India has tense relations with Pakistan; the two nations have gone to war four times: in 1947, 1965, 1971, and 1999. Three of these wars were fought over the disputed territory of Kashmir, while the fourth, the 1971 war, followed from India's support for the independence of present-day Bangladesh (Center for Arms Control and Non-Proliferation, 2019).

India is one of the very few countries with nuclear weapons. India's loss to China in the 1962 war, provided the government impetus for developing nuclear weapons as a means of deterring potential Chinese aggression. By 1964 India was in a position to develop nuclear weapons. India has a declared nuclear no-first-use policy and is in the process of developing a nuclear doctrine based on "credible minimum deterrence." (Government of India, Ministry of External Affairs, 1999).

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[21] Often also referred to as Human-Machine/System Integration/Interaction/Teaming.

After the 1965 war with Pakistan, India began to pursue close military and economic ties with the Soviet Union. By the late 1960s, the Soviet Union was India's largest arms supplier. Although India is globally the second largest importer of military systems, India also has a history of independently developing and manufacturing some of its own weapons. In the 1960s, India developed its own fighter jet. In 1974, it had its first successful nuclear bomb test. In 1983 its first indigenous frigates were commissioned, in the 1990s it developed ballistic missiles, and in 2004 it deployed its first locally developed tanks. Being torn between either relying on import or own manufacturing has led to a struggle of integrating new technologies into its wartime strategy and tactics. This has India often put behind the curve. Because India's military has not benefitted from advanced technology in battle, the Indian government has not thought defence technologies to be a vital part of security. Prior to 2017, most available annual reports published by India's Ministry of Defence, as well as other strategic documents, did not highlight technology as a priority (Nagao, 2020).

Thus, the year 2017 is seen as a turning point in India's technology and innovation approach. The "Joint Doctrine Indian Armed Forces" was published and clearly states that "defence technology is a strategic resource." (Indian Ministry of Defence, Headquarters Integrated Defence Staff, 2017) Also, the 2018 "Land Warfare Doctrine", addressing extensively the relevance of defence technology and initiatives like the establishment of a Task Force on AI underline this change in approach (Indian Army, 2018).

Nevertheless, Indian bureaucracy is still a bottleneck in speeding up the innovation. Although there are many plans and ambitions, some well reputed Indian think tanks do not foresee a dramatic transformation over the coming 10 years (Bommakanti, 2021).

4.2.2 Research, Technology and Development in general

In the period 2015 to 2020 the government has fostered a large number of policies and programmes to encourage an innovation culture and absorb major emerging technologies such as AI, blockchain and electric vehicles. However, the persistent shortage of well-trained scientists and engineers is an obstacle to the percolation of these technologies through the economy.

Another impediment is insufficient domestic investment in research and development (R&D). On the positive side, intangible investments by private corporations are on the rise, as is investment in R&D by foreign multinational corporations. One of the fastest-growing research topics has been sustainable transportation and energy, due to environmental challenges (pollution) India is facing (UNESCO, 2021).

Roughly 42% of India's R&D spending is in the private sector, while the remaining 58% is public spending (by the government). Half of the public R&D spending is dedicated to Defence and Space (Ramesh, 2021). Under the 'Make in India' mission, defence has been identified as one of the most promising sectors, contributing towards external and internal peace and security as well as socio-economic development of the country. By 2030, India's aerospace and defence industry is estimated to reach a market valuation of around $70 bn, which would be twice as much as the UK currently. According to government data, India has around

194 start-ups in the defence-tech space that are leveraging new-age technologies to come up with solutions for empowering the nation's defence and security. Looking at the potential the Indian start-ups possess and trying to encourage their efforts, the government has plans to fund at least 250 defence start-ups over the next five years (Chowdhry, 2021).

<u>Make in India mission and Defence</u>
The Indian government has as part of its 'Make in India' programme, given a new impetus to the development of defence production in the country both for its need and also for exporting to friendly countries. India has become one of the largest importers of defence goods and services in the world. The 'Make in India' mission has to change this. It strives to make India among the top five countries of the world in Aerospace and Defence industries, from design to production, with active participation of public and private sector fulfilling the objective of self-reliance as well as demand of other friendly countries. R&D and innovation are considered to be very important determinants of defence production capabilities. The R&D strength of India needs to be channelised for creating domestic IPR for defence needs. With the launch of Start-Up India program, India has also become the hotspot of start-up activity in the world, having the third-largest start-up ecosystem globally. These strengths need to be leveraged to catapult India as a developer of next level of frontier defence technologies in the world, in the field of aerospace and defence (Government of India, Ministry of Defence, 2018).

<u>Relevant Defence Departments</u>
Within the Indian Ministry of Defence there are two departments that are strongly related to defence R&D: the department of Defence production and the department of Defence Research and Development (referred to as DRDO). The Department of Defence Production was set up in 1962 with the aim to make India more self-reliant instead of being a full importer of military systems and equipment. The Department also recognises that true self-reliance is only possible when the technology is also from its own country. Therefore stimulates innovation and Intellectual Property creation in India's defence industry ecosystem which has led to developing a wide range of military capabilities. The DRDO, advises the government on scientific aspects of military equipment and logistics and the formulation of research, design and development plans for equipment required by the armed forces (Government of India, Ministry of Defence, 2020). DRDO has a total strength of 24,732 employees, of which 6,255 are staff employees. It was set up in 1958 and at present is a network of more than 50 laboratories in different cities of the country. During the financial year 2018-19, which provides to date the latest official financials, DRDO has been allocated 6% of the total Defence Budget.

<u>Technology Perspective and Capability Roadmap</u>
Once per 5 years a Technology Perspective and Capability Roadmap (TPCR) is developed by the Indian MoD. The TPCR provides to the industry an overview of equipment that is envisaged to be inducted into the Indian Armed Forces within 10-15 years. The latest edition is the TPCR-2018 which demands for new capabilities up to the end of the 2020's (Government of India, Ministry of Defence, 2018). The TPCR provides details of quantity, life cycle, performance parameters and preferred technologies that have been included in the capabilities, to the extent possible.

The latest innovation and technology reforms and initiatives:

- Engaging industries has led to partnering with over 1000 companies in DRDO's development programmes.
- Intensifying international collaboration on R&T resulted in new MoUs (memorandum of understanding) signed with over 30 countries worldwide.
- The creation of advanced technology centres in 2020, which are dedicated to High Energy Materials, Cryptology, Composite materials, Life sciences, Sensors and Microelectromechanical systems, Propulsion Technology, Photonic technologies, Millimetre wave semiconductors.
- Launching the iDEX in 2018, which aims at the creation of an ecosystem to foster innovation and technology development in Defence and Aerospace by engaging Industries including MSMEs, Start-ups, Individual Innovators, R&D institutes and Academia and provide them grants/ funding and other support to carry out R&D (Government of India, Ministry of Defence, 2021).
- In 2020 the Indian army started to conduct a study on advanced niche and disruptive warfare technologies to strengthen its soldiers' war-fighting capabilities. The study included drone swarms, robotics, lasers, loiter and smart munitions, AI, big data analysis, algorithmic warfare, Internet of Things (IoT), virtual reality and augmented reality, hypersonic-enabled long range precision firing systems, additive manufacturing, biomaterial infused invisibility cloaks, exoskeleton systems, liquid armour, quantum computing, robotics, and directed-energy weapons (Army Technology, 2020). The results have not been publicly released yet.

4.2.3 Artificial Intelligence

Under the umbrella of iDEX, a task force was created in 2018 to study the strategic implications of AI in national security and defence needs and to make appropriate recommendations in this regard. One of these recommendations includes the establishment of the Defence AI Project Agency (DAIPA) with members drawn from Defence Services, academia and industry. DAIPA will have the prime responsibility of enabling the design, development and production of AI based systems and AI based processes across the services and other defence organisations.

AI based products under development by the government (or partly even being completed and implemented) are (Government of India, Ministry of Defence, 2020):

- Human Face Recognition;
- Voice Activated Command System;
- Automatic Target Recognition;
- Remotely Operated Vehicle (ROV);
- Unmanned Surface Vessel (USV);
- Unmanned Underwater Vehicle;
- Drone Assisted Mine Protected Vehicle.

Within the DRDO the Centre for Artificial Intelligence & Robotics (CAIR) is one of the defence research centres working in the field of AI (Defence Research and Development Organisation, 2021). New technologies that are worked on include:

- Automatic speech processing, solutions for speaker independent speech recognition and language independent speaker identification. Although Hindi is the official working language and officers are well trained in it, the large variety of Indian languages is still a bit of a struggle (Chatterjee, 2016). This might be

an explanation for the emphasis on automatic speech processing and translating.
- Intelligent and informed decision support for deployment, transport allocation, convoy composition and scheduling and coastal surveillance, using algorithms like Multi Criteria Decision Making (MCDM), swarm algorithms, game theoretic approaches.

Despite the aforementioned initiatives and developments there is criticism about their speed and strength. The TPCR-2018 for instance does not list a single project related to AI and robotics. The AI Task Force was neither initiated nor steered by the armed forces. In addition, there is criticism about the lack of synergy between military services, DRDO and academia (Panwar, 2020). Also the fact that India opened its first AI-focused research institute in Mumbai only in 2018, in contrast with many other countries that established AI research institutes long before, underlines India's slow start in this technology area (Christopher, 2018).

4.2.4 Cyber & Electromagnetic Activities

Despite the geostrategic instability of its region and a keen awareness of the cyber threats it faces, India has only made modest progress in developing its policy and doctrine for cyberspace security. The Ministry of Communications and Information Technology released the country's first National Cyber Security Policy in 2013. A new national cyber-security strategy was planned to be released in 2020, but that effort appears to have stalled.

As a nuclear power with a large conventional force, a burgeoning digital economy and a determination to increase its geopolitical influence, India is the target of cyber espionage by a wide range of states. However, it knows its defensive capabilities are relatively weak. As a result, it pursues diplomatic efforts to bring the governance of cyberspace within the rules-based international order (cyber diplomacy), while maintaining a realistic approach to dealing with the states that are targeting its networks (International Institute for Strategic Studies, 2021).

The strengths of the Indian digital economy include a vibrant start-up culture and a very large talent pool. The private sector has moved more quickly than the government in promoting national cyber security. It also recommended the government to intensify developing cybersecurity technology, develop training infrastructure, invest in testing labs, actively participate in making technology standards, demonstrating India's capabilities in the global market, and improve preparedness of small and medium enterprises (Data Security Council of India, 2020).

From a military perspective concerns about cyber security have heightened since the military confrontation with China in the disputed Ladakh border area in June 2020, which was followed by a sharp increase in Chinese activity against Indian networks. The brief but debilitating October 2020 electrical blackout in Mumbai through a cyberattack by Chinese hackers was just a mere example of China's intensified cyber-attacks against India (Sanger & Schmall, China appears to warn India: push too hard and the lights go out, 2021). Another, directed against India's defence infrastructure, was the targeting of Indian defence research by a Chinese state-backed hacker group in the first half of 2021 (Recorded Future, sd). From the little evidence available on India's offensive cyber capability, it is safe to assume it is Pakistan-focused and regionally effective (International Institute for Strategic Studies, 2021). However, there are some indications that the focus may have shifted more to countering China, given its growing economy and regional power.

In the area of Electromagnetic (EM) activities, one of India's focus points is the use of jamming drones. On the 27th of June 2021, small drones were used to target the Jammu air force station. This attack was the first-ever offensive use of drones to target an Indian military facility. Therefore DRDO is working on counter-drone technology using variety of methods to neutralise the danger from such aerial attacks. Methods include jamming the hostile drone and a laser-based kill system (Singh, Our anti-drone technology can stave off threats: DRDO chief, 2021).

4.2.5 Quantum

Quantum technology has been given a massive boost in India's latest budget, receiving $1.12 bn over five years (2020-2024) as part of a new national quantum mission, to be administered by the ministry of Science and Technology. In 2018, a quantum-technology research programme received $27.9 mln over five years, as part of the National Mission on Interdisciplinary Cyber-Physical Systems. The new mission will oversee the development of quantum technologies for communications, computing, materials development and cryptography. For India it is now time to make the transit from the theoretical side to building infrastructure, experimental facilities and capacities (Padma, 2020).

The strong support in funding and infrastructure has already inspired many private players, in particular start-ups, to make inroads into the domain. These players are involved in quantum computing software solutions, hybrid classical-quantum computers, quantum security (QKD), quantum machine learning and artificial intelligence (Analytics India Magazine, 2021).

Also in the defence domain, quantum research has been taken to the next level. In December 2020, the DRDO announced that its Young Scientist Laboratory for Quantum Technologies (DYSL-QT) has developed a Quantum Random Number Generator (QRNG) which detects random quantum events and converts those into a stream of binary digits to be used for random numbers (Government of India, Ministry of Defence, 2020). Random numbers have essential roles in many fields, such as quantum communication, cryptography (key generation, key wrapping, authentication etc.), scientific simulations, lotteries and fundamental physics experiments. The generation of genuine randomness is generally considered impossible with classical means. In another advance at the end of 2020, DRDO demonstrated secure communication using Quantum Key Distribution (QKD) technology between two DRDO labs in Hyderabad, which is important since quantum based communication offers a robust solution to sharing the keys and hence data securely (Government of India, Ministry of Defence, 2020).

Now, India is starting to align quantum research initiatives in both the defence and civil domain. In July 2021 the Defence Institute of Advanced Technology (DIAT) and Centre for Development of Advanced Computing (C-DAC) have signed a MoU to collaborate on the development of quantum computers. DIAT is a research and academic institution under the Department of Defence Research and Development and C-DAC is the premier research and development organisation of the Ministry of Electronics and Information Technology (Express News Service, 2021).

4.2.6 Sensor

India is developing a wide range of sensor technologies. One of its current highly ambitious projects is the development of a dome antenna for the airborne early warning system. Critical technologies and components include the structure of the dome, the liquid cooling for airborne use, the composite radome to meet the challenging environmental requirements, and transmitter/receiver modules. India also plans for AI in future airborne surveillance systems in order to provide faster and more efficient and accurate systems (Defence Research and Development Organisation, 2021).

As already mentioned the attacks by drones is a serious threat to the armed forces. This is imperative in the backdrop of the government opening up the skies to privately owned UAV's and the growing security threat posed by rogue drones. DRDO therefore is developing a new electro-optical system for tracking drones. The system should be able to detect a four-feet long UAV flying at about 300 km/h from a distance of 3 km and a drone having a size of about one foot and flying at about 70 km/h from a distance of 2 km. The system will use thermal imagers, high-resolution video cameras, laser illuminators and laser range finders to detect and track drones. It will also be capable of being integrated with airspace surveillance radars (Mohan, 2021).

In the naval domain India is developing and implementing the USHUS-2 Integrated Submarine Sonar System. USHUS-2 sonar suite includes Passive Sonar, Active Sonar, Intercept Sonar, Obstacle Avoidance Sonar and Underwater Telephony. The system is considered to be state-of-the-art since it provides advanced classification features, contact motion analysis and automatic torpedo detection capabilities (Defence Research and Development Organisation, n.d.).

4.2.7 Man Machine integration

There was no specific information found about military human-machine integration developments in India. However, the increase of automation and autonomous systems will have a large impact on India's society and will transform it civil sector substantially. As India enters the era of robots and AI, most companies plan to automate jobs to compete on cost. But will replacing humans with machines really turn India into a global economic powerhouse? The World Economic Forum's Future of Jobs 2018 report suggests that a more effective strategy could be to train its workers for the future, giving them the skills they need to work with sophisticated machines, data and algorithms (World Economic Forum, 2018). Man-machine integration through interactive technologies will be a critical factor in realising this goal.

Rapid advancement of interactive technologies during the past two decades has made access to information easier. There is a generation who grew up with these technologies and another generation who find many modern electronic systems counter intuitive and have no use for them in their daily life. This digital divide becomes more prominent in developing countries, like India to some extent still is, as state-of-the-art interactive systems were not and are still not affordable to a large number of users. For India to close this gap, it would require building on the existing strengths of India's workforce, from analytical thinking and innovation, to technology design and programming. However, Indian engineers and computer scientists have thrived at multi-national companies from Google to Microsoft. In the future, such local talent is needed ‘at home’ to power Indian innovation in interactive technologies. (India Online Pages, 2021).

4.2.8 Weapons

India is pursuing both hypersonic and directed-energy weapons. The Technology Perspective and Capability Roadmap released in 2018 previewed more than 200 pieces of equipment envisaged for introduction in the military in the late 2020s. Among the list of projects that the industry was encouraged to pursue was a tactical High Energy laser system for the army and air force. It is envisaged that these systems should be capable of being effective against soft skinned vehicles and troops up to ranges of 20 km, both in ground-to-ground and ground-to-air roles. Also high power EM weapons systems are a requirement for the near future, to be employed against electronic and electrical systems and ranges of 8 km or more. These should be effective against cellular and microwave towers, communication networks, aircraft avionics and radars, and unmanned aerial vehicles (Government of India, Ministry of Defence, 2018).

On September 9 2020 India conducted a successful test of a fully indigenous hypersonic technology demonstrator vehicle powered by an air-breathing scramjet engine. According to DRDO, the successful demonstration proved several critical technologies including aerodynamic configuration for hypersonic manoeuvres, the use of scramjet propulsion for ignition and sustained combustion at hypersonic flow, thermo-structural characterisation of high-temperature materials, separation mechanism at hypersonic velocities. The scramjet technology gives the missile the ability to fly at Mach 6 (six times the speed of sound).[22] India is also developing the hypersonic BrahMos-II cruise missile in close cooperation with Russia. Russia is developing a special and secret fuel formula to enable the BrahMos-II to exceed Mach 8 (Reghuvanshi, 2020).

In order to boost India’s firepower the DRDO is gearing up to provide the Indian military with a dozen new indigenous weapons and systems over the next two years, mainly to strengthen its capabilities include beyond visual range (BVR) missiles and improved precision. These weapons include anti-radiation missiles, anti-tank weapons, anti-drone systems, guided bombs and anti-airfield weapons. Most of these weapons will come into service in the next 2-3 years and are rather mainstream weapons. When looking beyond this short term period, India is also developing more advanced weapons, like the supersonic missile-assisted release of torpedo (SMART) to target submarines at long ranges and the stand-off anti-tank missile (SANT), armed by a helicopter with the capability to destroy enemy armour from an improved stand-off range (5-10 km) (Singh, How India aims to boost its indigenous defence capabilities in two years, 2021).

Being one of the few nuclear powers India is currently improving its Nuclear Triad[23] by improving the mobility of land-launched nuclear missiles and developing nuclear-capable, submarine-launched ballistic missiles (Davenport, 2020).

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[23] A nuclear triad is a three-pronged military force structure that consists of land-launched nuclear missiles, nuclear-missile-armed submarines, and strategic aircraft with nuclear bombs and missiles.

4.2.9 Space

Most of India's space research and development activities are performed and/or supervised by the Indian Space Research Organisation (ISRO). It operates under the Department of Space (DOS) which is directly overseen by the Prime Minister of India. It is one of six government space agencies in the world which possesses full launch capabilities, deploys cryogenic engines, launches extra-terrestrial missions and operates large fleets of artificial satellites. The cryogenic rocket engine technology will enable Indian rockets to carry heavy satellites into the space and thereby to haul heftier payloads to Earth's orbit and toward interplanetary destinations (Narasimhan, 2014). In addition, India is also investing in micro-satellites. An example is the Anvesha micro-satellite, flying in low orbit (<500 km) and equipped with hyperspectral imaging payload, for early warning and surveillance (Indian Defence News, 2020).

India's space goals in the near future include expanding its satellites fleet, landing a rover on Moon, sending humans into space, development of a semi-cryogenic engine, sending more unmanned missions to moon, Mars and Venus, and deployment of more space telescopes in orbit to observe cosmic phenomena and outer space beyond the solar system (Semeraero, 2020).

On the military side India has developed its anti-satellite missile, which was tested in March 2019, by destroying one of its own satellites (Press Trust India, 2019). The test made India the fourth country after the United States, Russia and China to have tested an anti-satellite weapon. This capability can also be used to strengthen India's Ballistic Missile Defence systems.

4.2.10 3D printing and new materials

3D-printing technology is seen as being very useful to the Indian armed forces, including for the production of hard-to-find spare parts for legacy equipment. Early 2021 the Indian Air Force has for the first time released a request for proposal to industry for 3D-printed components, including the development of flat washers for the Snecma M53 jet engine for the Mirage 2000-5 fighter (Mathews, 2021). However, the real boost for using 3D printing in the armed forces has still to come.
The main DRDO laboratory working on new materials is the Naval Materials Research Laboratory (NMRL). It has developed the following technologies for protection of Indian Naval platforms (Defence Research and Development Organization, 2020):

- Protective coating for corrosion prevention;
- Heavy duty non-skid paint preventing the skidding of personnel and aircraft on flight, of helicopters and of decks on naval ships;
- Anti-corrosive and anti-fouling paint for underwater applications; it provides e.g. a solution for on-site maintenance painting without bringing the ship to dock;
- Self-cleaning coating, ensuring self-cleaning of dirt and contaminants, while the epoxy layer underneath provides anti-corrosive properties and adhesion to metallic substrates.

Another line of research in new materials is related to nano materials (NMs). There is a growing need and tendency to use NMs in military applications. In India research is done on toxicity characterization of NMs, so that the health of army personnel as well as civilians can be properly safeguarded. Toxicity characterization has been based on size, morphology, and surface charge on the circulation half-life and interaction of engineered NMs with biomolecules. Long term objective is to evaluate the key biological effects of NMs upon contact with the biological system such as bio-distribution, circulatory half-life, mechanisms of phenotypic and genotypic toxicity and transmission to generations (Defence Research and Development Organization, 2020).

4.2.11 Biotechnology

With the advent of -omics technologies (genomics, transcriptomics, proteomics, metabolomics, etc.), the data in biological sciences is increasing exponentially. This valuable data is scattered, unstructured, voluminous and is deposited unregulated in the public domain. Therefore, the DRDO has established a Bioinformatics Lab to develop and apply tools and databases by which biological science data can be systematically compiled, curated, annotated and analysed (Defence Research and Development Organization, 2020).

The North-East region of India is one of the most biodiverse hotspots of the world, full of numerous indigenous flora and fauna, forests, hills, streams, rivers and lakes. This region presents unique challenges to the armed/paramilitary forces deployed there. The main problems are associated with contaminated drinking water, lack of proper sanitary disposal, high density of disease vectors, hematophagous insects like mosquitoes, ticks, black-flies, leeches, snakes prevalence of fungal pathogens and dermatophytes and also poor availability of fresh fruits and vegetables in remote and high altitude locations. Therefore Indian biotechnology research tries to develop innovative solutions to counter or mitigate the aforementioned challenges. Research topics and solutions are:

- Low cost field deployable tests for pathogen detection, suitable for surveillance and monitoring of a wide range of vector borne and other pathogens.
- Nano-technology for the removal of contaminants from water and mosquito larvicidal agent. Locally available plant resources and waste food stuffs have been Utilised to synthesise nanomaterials. These nanoparticles are found effective for removing arsenic and fluor from contaminated water and in controlling bacteria.

Due to the severe impact of COVID-19 in India the DRDO is amongst other national institutes requested by the Vice President to intensify biotech research to combat any pandemic threat in the future. This would imply the development of products and equipment (e.g. vaccines, testing) for treatment and management of COVID-19 and new variants of SARS-CoV-2 (India Education Diary, 2021).

4.2.12 Simulation and virtualisation

In September 2021 the MoD released its policy for enhanced utilisation of simulators by armed forces to impart safe and cost-effective realistic training while preserving expensive equipment. The policy seeks to reduce live equipment utilisation, ensure capability plans cater for phased induction of simulators, factor in the requirement of simulators when procurements are planned and create a coordination mechanism among various agencies for a combined purchase of simulators. The use of simulation is expected to reduce defence spending when military budgets are under pressure because of the impact of the Covid-19 pandemic on the economy. Although the value of simulators has been long recognised within the Indian MoD, investments have so far been modest.

The MoD also strives to profit from India's growing gaming industry. In the last 5-8 years, the gaming industry in India grew at a healthy pace. The number of gamers in India has increased at a rapid pace owing to the increasing smartphone penetration and better internet connectivity coupled with improving telecom infrastructure in the country. As a result, India has globally become the centre for outsourcing work such as game development, game support services, etc. Few of the major emerging trends in the country's gaming industry include growing adoption of Augmented Reality and Virtual Reality technologies, adoption of Platform as a Service for easy game creation, concept of soft monetisation, freemium games, among others (Confederation of Indian Industry, 2017). Although no specific information about applying gaming technologies in the military domain was found, one can expect that the aforementioned technological developments will also gaining terrain in education, training and exercises for the military.

4.2.13 Human Performance and Training

Due to India's varying and challenging terrain and climate conditions, physiological research is of utmost importance. Technologies for acclimatisation, rapid induction and sustaining health at higher altitudes (more than 2700 meters above sea level) is performed by the life sciences institutes and laboratories under DRDO (e.g. Defence Institute of Physiology and Allied Sciences (DIPAS)). Research is dedicated to mitigate the negative effects of hypoxic environment, sub-zero temperature and intense UV radiation, on efficiency and cognitive functions of a human being. Based on research and experiments acclimatization schedules (staging of acclimatization) are developed for the induction of Indian troops at high altitudes based on detailed longitudinal studies using physiological, psychological, biochemical, and hormonal profile assessment of soldiers under high altitude conditions. Also the developments of therapeutics, pharmacological agents and nutraceuticals for high altitude acclimatisation are part of this research area (Defence Research and Development Organization, 2020).

Another challenge for Indian troops is operating in the hot and dry Thar desert and the wet swamp of the Rann of Kutch. Decreased performance due to high ambient temperature, intense solar radiations, hot winds and loose sandy terrain are natural threats when operating in the desert. Therefore research is done on energy expenditure and nutrient support.

An interesting and well fitted approach in Indian culture is the use of Yoga in the armed forces. Study results about beneficial effects of yoga on body homeostasis and performance, both mental and physical, of soldiers under different climatic extremes and training, showed that yoga improves not only pulmonary and cardiac functions but flexibility also. Yoga packages (General Health, Extreme environments, high altitude, navy sailors and submariners, air force and desert) have been developed keeping in view specific needs and physiological changes taking place under different environment and occupational needs (Defence Research and Development Organization, 2020).

In the field of ergonomics, research and technology developments are undertaken in different areas of ergonomics like physical ergonomics, design ergonomics, neuro-ergonomics. Studies involve (Defence Research and Development Organization, 2020):

- Integrated 3D motion analysis for simultaneous measurement of kinematic, kinetic and EMG parameters during human motion like gait while walking, running, using prosthetics and orthotics, load carriage.
- Portable breath by breath metabolic measurement is undertaken for measuring physical work load during different activities like walking, running, load carriage on level ground, altitudes and different terrains like snow, jungle, sand, etc.
- Portable Eye Tracking Glasses, with data acquisition and analysis software, are used to assess mental or cognitive work load.
- Human modelling and simulation for proactive ergonomics assessment of Human-Machine interfacing issues and designing of military workstations, vehicles, equipment and weapon systems.

4.2.14 Robotics and Autonomous systems

Humanoids robots have been gaining popularity in India for quite some time now. Although the country is still catching up with the developments in AI and robotics as compared to others, Indian start-ups, as well as the government, are working at a rapid pace to integrate new-age technologies. According to International Federation of Robotics research, India is ranked 12th worldwide in annual installations of industrial robots (International Federation of Robotics, 2021).

The Indian armed forces are gradually moving towards inducting ground-based unmanned vehicles. In 2019, the Indian Army unveiled the autonomous surveillance and weapons platform. The Indian Army already operates Daksh, which is a battery-operated, remote-controlled robot on wheels used primarily for bomb recovery (Smruti, 2021).

The Navy is in the process of procuring mine countermeasure vessels capable of launching, recovering and guiding Expendable and/or Reusable Mine Identification & Disposal Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs)/Propelled Variable Depth Sonar (PVDS) able to operate in autonomous, semi-autonomous, supervised or in tethered mode, and capable of operating in wide range of depth from shallow to deep waters and have extended endurance (Manaranche, 2021). Although Indian intends to become more self-reliant on technology, this example shows that on the robotics side technology and capabilities are also procured from abroad.

As we have seen, India is progressing in the area of robotics, but it still does not have very advanced AI robotics. This is due to its slow pace with respect to AI developments. Currently, India is mainly working on pre-programmed robots. In August 2018, India and Japan’s Ministries of Defence signed cooperative research agreements in the areas of robotics and unmanned ground vehicles (UGVs) (Embassy of Japan in India, 2018). It is expected that the joint development of UGVs will over time include AI-related research. India’s future use of UGVs is, amongst others, dedicated to patrolling the Indo-China border.

Currently, India’s most advanced developments are in the field of swarming concepts for drones. The Indian army during Army Day in 2021 demonstrated a swarm attack by drones on multiple targets. The demonstration included a fully operational decentralised swarm of 25 drones flying with minimal human intervention (Singh, DRDO displays drone swarmin offensive role, 2021).

4.2.15 ICT and networks

More than two decades ago, India began its transformation into a global IT powerhouse, leading to an increase in wealth and job creation never before seen in the country. The Covid-19 pandemic has forced business in India and all other countries around the world to make huge investments in digital infrastructure, furthering the influence of companies providing software-as-a-service (SaaS). India's software-as-a-service industry could be worth $1 trillion in value by 2030 and create nearly half a million new jobs, according to a recent report. SaaS is a potential key area for C4ISR in the armed forces. For example, it enables military users to access the data they need wherever they are, whether they are on a mobile device or not. It also allows users to more freely share data while still doing it in a secure mode. Overall, SaaS tools give the armed forces greater flexibility and make the command more efficient. Whether India will walk this path successfully, is still to be seen. Just as whether SaaS innovations will be spun into the Indian armed forces (Garg, 2021).

The largest ICT/C4I program currently running in the Indian armed forces include the army’s long-awaited procurements like Battlefield Management System (BMS) and Tactical Communication Systems (TCS). Both may become a reality soon. BMS is a situational awareness and visualisation system that aims to optimise the operational effectiveness of tactical units. It is envisaged that it will cover more than 70% of the soldiers while digitising the tactical battlefield and creating a secure IoT for the army (Mekala, sd).
In addition to the deployment of BMS the army’s emphasis is on (Confederation of Indian Industry, Army Design Bureau, 2016):
(a) Lighter fieldable C4I[24] devices with long battery life;
(b) Integration of various and diverse existing communication equipment and systems;
(c) Security of communications, devices and applications;
(e) Spectrum and bandwidth management as data requirements increase and move towards wireless devices;
(f) Applications development, military, like others, would like smart phones to provide multiple benefits including applications designed for military use;
(g) Cloud computing;
(h) Data analytics.

4.2.16 Behavioural engineering

We did only find open source information about disinformation in general and partly related to the military. Investments, plans and ambitions with respect to other behavioural engineering activities (like psy ops) has not been found.

The (ab)use of disinformation is a devastating problem in India, and is still growing. More than 400 million Indians now use the internet, but digital literacy and social media regulation have yet to catch up. Also cultural and religious differences and fault lines in Indian society have caused people to follow through on fake news. While there are several fact-checking organisations, their efforts are often overwhelmed by the volume of fake news being circulated. Using artificial intelligence to counter fake news is still scarcely used (Saxena, 2021).

[24] Command, Control, Communications, Computers, and Intelligence.

Disinformation efforts in India have gained increased prominence and media attention as a result of the 2019 general election. There has been a mounting body of evidence demonstrating the growing capacity of cyber troops in India to carry out social media manipulation campaigns. In the lead-up to the 2019 general election, teams have been growing, new techniques have been tried and tested, and private companies were hired, all to give political parties a cutting edge during the campaigning periods (Campbell-Smith & Bradshaw, 2019).

The use of disinformation in a state-to-state competition or conflict is also a point of attention and even concern for India, especially in relation to India-Pakistan and India-China tensions. In 2019, the Ministry of Defence cleared an exclusive information warfare branch for the Indian Army to combat misinformation campaigns and propaganda being spread through social media for psychological conflicts. This plan was approved amid increased circulation of fake news about the military establishment, in particular propaganda being peddled on social media by Pakistan revolving around the Indian Air Force airstrike on a terror camp in Balakot (Bhalla, 2019).

4.2.17 Energy

According to the latest report of the International Energy Agency, India is in a unique position to pioneer a new model for low-carbon energy. India is already a global leader in solar power – and solar combined with batteries will play a massive part in India’s energy future. The pace of change in the electricity sector puts a huge premium on robust grids and other sources of flexibility, with India becoming a global leader in battery storage.

India’s armed forces will likely profit from energy innovations and transitions for the civil sectors. Some developments are already progressing, such as processing of biomass to bio-energy and biofuels. In recent years, the Defence Institute of Bio-Energy Research (DIBER), a premier Bio-Energy R&D laboratory of DRDO, has developed technologies for utilising pine forest residues for combined heat and power (CHP) by gasification. The institute has also developed another gasification process utilising pine needles as fuel, and steam as an oxidant for producing hydrogen rich syngas. The syngas itself can be used as a fuel in generator sets, engines and fuel cells. DIBER has also successfully conducted bio-diesel trials in vehicles and equipment of armed forces under very demanding environmental conditions (Defence Research and Development Organization, 2021).

Another development is fuel cell technology through the development of new materials, manufacturing processes, design approaches and product engineering. Naval Materials Research Laboratory (NMRL) has industrialised fuel cell-related materials, components and high power stacks based on Phosphoric Acid Fuel Cell (PAFC) technology through a comprehensive research initiatives. NMRL is working on developing indigenous Naval Air-independent propulsion (AIP) technology based on the PAFC power system. This marine propulsion technology will facilitate a non-nuclear submarine to operate without access to atmospheric oxygen by surfacing or using a snorkel. It will increase the underwater endurance of IN submarine with enhanced submerged period of conventional submarines (Defence Research and Development Organization, 2020).

4.3 Official sources

The table below shows a shortlist of the main official policy documents and sources that have been consulted.

Title	Objective	References
Ministry of Defence, Government of India, Annual Report 2018-2019	Provides an account of the activities and financials of the Indian Ministry of Defence during one fiscal year.	https://www.mod.gov.in/ documents/annual-report
Technology Perspective and Capability Roadmap (TPCR)-2018, Indian Ministry of Defence	Provides the industry an overview of equipment that is envisaged to be inducted into the Indian Armed Forces up to the late 2020s. It intends to drive the technology development process that the industry may like to pursue.	https://www.mod.gov.in/ sites/default/files/tpcr.pdf
DRDO Technology Focus	No formal policy documents on R&D were found. Nevertheless, the DRDO website provides Technology Focus briefs/newsletters which are issued every 2 months and deal with a specific technology area.	https://www.drdo.gov.in/ technology-focus

There are other official sources available via Open Source (e.g. the MoD’s website) but they date from 2013 and long before. This could be a result of becoming more restrictive in publishing information or due to India’s bureaucratic processes which delay either the publishing of formal documents or new policymaking and planning.

5 Israel

5.1 Overview benchmark results

5.1.1 General data and assessment results

The table below presents key data that reflect Israel's geopolitical challenges and drivers as well as its strengths and genera are all growing the l facts relevant to the defence and security environment.

ISRAEL: GENERAL INFORMATION	
Geopolitical challenges and drivers	• Arab-Israeli conflict • Small country surrounded by several rivals on its borders
Strengths	• Strong national defence industry and independent R&D capabilities • An enormous innovative capacity, including by combining old and modern technologies • Unique state of the art weapon systems • A strong relationship between the Israel Defence Forces and the civil and defence technology industry
Defence budget [2020]	• $22 bn (5,6% of GDP) (SIPRI, sd) • An additional $35 bn over a period of ten years in military support from the US • $2,508 per capita • 12% of total government budget
Defence size [2020]	• 170.000 active personnel (est.) (Global Firepower, 2021)
Defence R&T budget [2018]	• 8% of the defence budget for R&D purposes (Pinchas & Tishler, 2019) • 2% of the defence budget for basic and applied research activities (Pinchas & Tishler, 2019)
Defence R&T partner countries	• Most prominent partners: US (missile defence technology & Joint Strike Fighter), India (drones & robotics)
Arms industries	• Elbit Systems, Israel Aerospace Industries (IAI) and Rafael,
Arms export [to]	• Israel exports arms to around 130 countries (American Friends Service Committee, 2020). • In 2019, 41% of defence exports were to Asia and the Pacific (India as largest arms market), 26% to Europe, 25% to North America, and 4% to Latin America and Africa (Campaign against arms trade, 2021).
Arms import [from]	• US, Germany, Italy, UK (Campaign against arms trade, 2021)

The following table provides a summary of the key findings for each of the 15 SKIA technology areas. The column 'Focus' indicates the level of priority the referent country gives the respective technology area vis-à-vis other technology areas: high (+), moderate (0) or low (-). This reflects the governmental attention, based on policies, plans and investments, as well as concrete activities in research, technology and innovation. Also, it demonstrates the level of technological development that one can expect from a powerful military player.

ISRAEL: TECHNOLOGY AREAS			
	Technology Areas	**Focus (+,0,-)**	**Findings**
1	Artificial Intelligence	+	• Military Intelligence Unit research to exploit AI in war, predict enemy rocket launches, place, and time. • AI R&D to reduce the manning of weapon systems from three to two. For example the Carmel project for the future combat platform for land warfare. • Smart City Tech projects aim to make urban living more sustainable by researching possibilities for automation and digitising interactions between technologies, people and the physical environment.
2	Cyber & EM	+	• Israel is one of the most advanced global cybersecurity and cyber-defence players. • Israeli Fintech industry is a frontrunner in financial innovation. Blockchain can be used to e.g. prevent cyber-attacks, defend critical weapon systems, manage automated systems or manage logistics. • Military Intelligence veterans launch successful start-ups, predominantly in cybersurveillance (80% of cyber start-ups in 2018 were from veterans).
3	Quantum	+	• In 2020, the Israeli government approved $387.5 mln to invest in quantum research and capabilities.
4	Sensor	0	• Underground border sensors to detect tunnels. • New technology centre to produce non-GPS navigation systems using inertial sensors
5	Man Machine Integration	-	• 69% of Israeli cognitive-aware businesses view the future workforce as augmented, meaning that employees will either have new positions influenced by AI or will experience being augmented by cognitive technologies, like natural language processing.
6	Weapons	+	• Cooperation with the US Missile Defence Agency on the next-generation Arrow 4 air defence missile, including defence against hypersonic missiles. • Important player in terms of missile systems for offensive use (anti-tank and anti-ship) • New airborne laser weapon has an operational prototype by 2025.
7	Space	0/+	• Aims to position itself as a space-technologies hub, but the number of start-ups is still relatively low. • One of 13 countries with satellite-launching capabilities. • Defence Space Administration multi-year space and satellite development programme. Leading the way is the Ofek satellite series
8	3D printing & Materials	0	• The Israeli MoD and IAI produced the country's first 3D-printed UAV. • New survivability technology 'Kit 300' that can hide soldiers from infrared sensors.
9	Biotechnology	0	• Governmental investments in 'bio-convergence', including agrotech • Start-up sector still pales in comparison to e.g. cybersecurity
10	Simulation & virtualisation	0/+	• Digital battlefield technology, an augmented-reality system: the Fire Weaver
11	Human Performance & Training	0	• Israel Defence Forces combat training facilities that mock Lebanese villages to practise urban combat • Similar experience is offered in digital space

ISRAEL: TECHNOLOGY AREAS		
Technology Areas	**Focus (+,0,-)**	**Findings**
12 Robotics & Autonomous systems	+	• Israel is among the world's leaders in the development and use of UAVs. • UGV Jaguar to patrol the border with Gaza • New UGV four-wheel-drive robot, REX MKII, which gathers data and learns from it.
13 ICT & networks	+	• BNET software defined radio system delivering wideband communications with low delay and reliable connectivity. • C4ISR system, TORCH 750, provides a real-time picture of blue and red, and links the three IDF branches, creating a network for the multi-domain battlefield.
14 Behavioural engineering	-/0	• The Israeli-Palestinian conflict has witnessed a lot of misinformation efforts from both sides. • Otherwise, no information can be found on behavioural engineering investments.
15 Energy	-	• The government aims to generate 30% of electricity from renewable sources by the end of this decade and to become a net zero carbon economy by 2050. • Limited information available concerning the armed forces.

5.1.2 *Takeaway's*

The key takeaway's for the assessment of Israel's ambitions and activities in military science and technology are:

- Israel is surrounded by enemies in its direct environment and has adapted the strategy, structure and priorities of its armed forces accordingly. The Israel Defence Forces (IDF) have primarily expanded unconventional capacities and cyber and intelligence units.
- Israel is investing a lot in education. This includes universities in general as well as offering educational opportunities within several MoD branches for applicants to be trained in the field of cyber. Also, investments are made in veterans to be schooled in e.g., cyber, biotech or fintech to continue with relevant innovative work that would benefit the MoD.
- In practically every technology area, there is a great deal of cooperation between the military and the private sector (including defence institutions, academia, investors and arms manufacturers). This is largely due to the Israeli culture of conscription, but also because of the investments in education. These collaborations make the process of innovation more efficient and effective.
- Libertad Ventures, the Mossad's Technological Innovation Fund, focuses on two technology areas which are currently not covered by the 15 SKIA technology areas and that might be interesting for the Netherlands: Fintech and Smart City Tech.

5.2 Benchmark analysis

This subchapter presents the actual benchmark analysis upon which the table above and the key takeaway's are based. It starts with an introduction, after which it zooms in on Israel's research, technology and development base in general. Following, it analyses each technology area more in-depth. It ends with a concise table with the most important official sources used.

5.2.1 Introduction

The development of Israel's defence industry is closely related to its geopolitical security context. As a country that is in a permanent state of competition with Arab countries and non-state actors around its borders, it has been forced to innovate. This has been largely driven by the realisation that Israel would never win based on sheer numbers and therefore a qualitive military edge has always been perceived as the way to deal with existential threats to the state. As a result, Israel's economy today is mainly based on the technology industry (Pinchas & Tishler, 2019). Even though Israel does not belong to the top ten military spenders in the world, in 2020 it spent $2,508 per capita and assigned 12% of its total government spending to defence. Visualised by Al-Jazeera, these figures show that Israel is in fact an outlier relative to some of the countries with the largest military expenditure in the world, including the US (Siddiqui, Hussein, Zaheer, & Haddad, 2021). Furthermore, Israel belongs to the top countries exporting arms in the world. In 2020, it was the 12th-biggest arms supplier with more than $345m in weapons sales to 16 countries (SIPRI, sd). This is a unique phenomenon and can be traced back to the country's size and its particular security needs (Pinchas & Tishler, 2019). This includes the need to be independent. Israel does not trust any other country with its safety. The large exports are a pure necessity to be able to afford such a military industry.

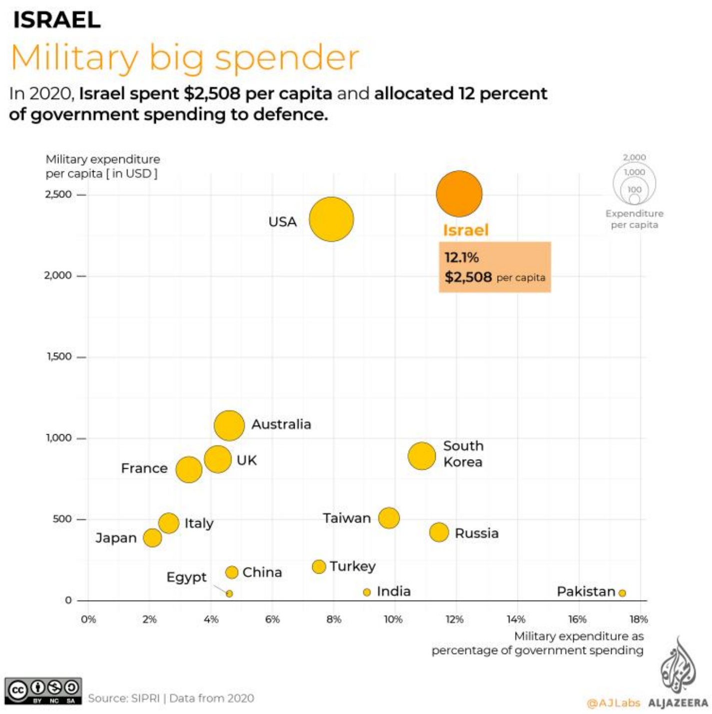

Figure 5 Mapping of countries on military expenditure, based on resp. government spending and per capita.

Israel is the biggest receiver of US military aid, with a total of $3.8bn in 2020 as part of a record $38bn deal across a 10-year period signed under former US President Barack Obama in 2016. It has been receiving over 55% of total US foreign military financing, more than the rest of the world has gotten combined. These figures exclude other indirect forms of military help, such as the emergency stockpile of US weapons stored in Israel (Siddiqui, Hussein, Zaheer, & Haddad, 2021).

In 2020, Israel spent 4,9% of its GDP on R&D, making it the highest in the world (Organisation for Economic, Co-operation and Develoment, sd). This creates a fruitful environment for innovation. Approximately a third of its R&D is spent on defence-oriented research. Israel, which is now referring to itself as “Start-up Nation”, has seen over 10,000 companies founded between 1999 and 2014, with 45% of the country’s exports being high-tech (Budden & Murray, 2019). The cultural values of innovativeness, but also creativeness and room for criticism across hierarchies, influenced by history of migration, further facilitate innovation (Tabansky & Israel, 2015).

Another important factor that has contributed to the level of entrepreneurship and thus the rise of Israel’s high-tech industry, is the mandatory military service for men and women at the age of 18. As a result, almost all political decision-makers, entrepreneurs, investors and corporate defence contractors have served in the military. This creates an ecosystem in which knowledge, social contacts, skills and other resources flow freely between the military and the civilian private sector, generating a general understanding of and support for the IDF (Swed & Butler, 2015) (Budden & Murray, 2019).

5.2.2 Research, Technology and Development in general

Israel aims to maintain independent defence R&D capabilities through the triangle of (1) the Directorate of Defence Research and Development within the MoD, (2) the technology and combat units of the IDF, and (3) the national defence industry. In contrary to most of the world’s large defence companies, the Israeli ones are (at least partially) government-owned. This includes Israel Aerospace Industries (IAI) and Rafael. The third top defence company, Elbit Systems, is privately-owned. The Israeli government encourages these companies to work together to expand their sales, but also to decrease possible commercial tensions. On the other hand, they are often also on purpose pitted against each other in order to increase creativity and innovation (like for example in the Carmel project, explained more in the AI-section, where all three brought their own solutions to the testing phase). Moreover, the good rapport between the military and the civilian industry is important to the IDF, as it buys most of its defence goods from local defence firms. At the same time, more complex platforms, such as fighter jets, submarines, small battle ships and some missile systems, are purchased from the US and some Western European countries (Pinchas & Tishler, 2019).

Israel has several (public) defence innovation agencies that contribute to the national R&D ecosystem. The three main organisations are discussed below.

<u>The Directorate of Defence Research and Development (DDR&D)</u>

The DDR&D, part of the Israeli Ministry of Defence, contributes to the development, production and maintenance of the (military) tools and technology used by the IDF and the entire defence establishment. One of its key responsibilities includes the development of innovative concepts for defence technology (Israeli Ministry of Defense, sd).

At its centre lies the Military Research and Development Unit, which has two main tasks: (1) to initiate and conduct research, advance development projects, and promote the technology and building blocks for future systems; and (2) to manage the progress of these projects and bring them to their full operational capabilities. It works together with academia, research institutes, high-tech companies, defence industries, and the military to match technologies and find solutions to operational problems (Israeli Ministry of Defense, sd).

Another unit within the DDR&D that contributes to the development of strategic capabilities is the Unit for Research and Technology Infrastructure. It is a scientific research organisation that aims to identify, develop and promote diverse tech solutions to address Israel's current and future security needs. The unit’s key focus areas are:

- Infrastructure, facilities and simulators;
- Quantum technology;
- Nanotechnology and micro-technology;
- ICT and autonomous protection;
- Physics, space and energy;
- Military medicine, ergonomics;
- Aerospace engineering;
- Chemical and energetic materials.

Three units within the DDR&D are each oriented towards one specific topic about:

- <u>Missile defence</u>: This division is responsible for the development, management and improvement of active (air) defence systems, including but not limited to interceptors, launchers, radars, command and control systems and network connectivity. Israel’s Missile Defence Organisation (IMDO) works in cooperation with the American Missile Defence Agency (MDA), on joint ventures, development and production (Israeli Ministry of Defense, sd).
- <u>UAV:</u> The UAV administration coordinates the development and production process of UAV elements, including communication systems, with the goal to develop cutting edge and cost-effective systems. Within the IDF, UAVs are primarily used for amongst others reconnaissance, infantry support and defence missions (Israeli Ministry of Defense, sd). However, there is a shift towards offence operations with loitering ammunitions becoming less costly, more reliable and easier to deploy and operate.[25]
- <u>Space and satellites:</u> The Space Administration is responsible for the development of satellites and launchers, with the aim to guarantee Israel's independence in space, thereby enhancing its strategic capabilities. Also, there is close cooperation with the high-tech (defence) industry (Israeli Ministry of Defense, sd).

<u>The Israeli Innovation Authority</u>
This is an independent public agency that coordinates industrial R&D cooperation and provides tools and platforms to aid local and international innovation ecosystems. It for example helps start-ups, innovative projects and entrepreneurs with advice on how to realise and implement ideas as well as grants and investments. Programmes include funding for high-tech and dual use technologies (The Israel Innovation Authority, sd). Together with the IDF and the National Cyber Bureau, the agency can coordinate a range of public sector resources (Budden & Murray, 2019).

[25] Information from interviews.

Libertad Ventures
The fund, established by the Mossad, invests in R&D projects of start-ups and entrepreneurs to strengthen the Mossad's technical capabilities and provide the intelligence service with an innovative edge. In return for funding the R&D programmes, the Mossad receives a royalty-free license to use the 'visionary' technology that is developed. Key areas of focus include: fintech, personality profiling, voice analysis, machine learning, robotics, big-data, AI, synthetic biology, data science, energy harvesting, 3D printing and scanning, smart city tech, drones, natural language processing, blockchain and perfect online privacy (Mossad, sd).

National defence strategy & priorities
The IDF published its first formal defence doctrine in 2015, which outlines the military's strategic and operational responses to the main threats facing Israel.[26] One of its principles signalling the security environment for the state of Israel is that it relies on an offensive posture. Moreover, it aims to maintain the relative advantage, based on amongst others advanced technological capabilities (Belfer Center, 2015, pp. 4-5). The doctrine outlines several capabilities that the IDF requires. For example, because high trajectory weapons are considered as the dominant component in Israel's enemy's offensive capabilities, the IDF focuses on "continuous integrated defence capable of dealing with a high flow of threats, which combines "soft" and kinetic capabilities to neutralise the enemy's precision firepower systems" as well as early warning capabilities. Throughout the document, the need for offensive (lethal), early warning, cyber and new technological capabilities are being emphasised.

To create its newest strategy to reform its armed forces, the multi-year plan 'Momentum', or 'Tnufa' in Hebrew, the IDF initiated four stages in 2019:
1) diagnosis, 2) formulation of a new activation concept, 3) shaping of principles for the future IDF, and 4) setting up planning frameworks for force build-up. (Lappin, The IDF's Momentum Plan Aims to Create a New Type of War Machine, 2020).

In 2020, Momentum was published (Ortal, 2020). It envisions a multi-front war, using the latest technologies, with a 'multi-force' that combines the arms of its naval, land, air, cyber and intelligence forces. It is focusing on so-called 'third circle' threats, such as Iran, as well as how to confront Hamas and Hezbollah. The plan is guided by three main efforts. First, the creation of a multi-domain ground manoeuvre capability, meaning that IDF field units are be able to operate simultaneously on the ground, underground, in the air, in the electromagnetic spectrum, and in the cyber domain. A second axis is based on upgrading Israeli firepower strikes. The third part is designed to boost defences for the Israeli home front. Concretely, this translates to enormous investments in developing the IDF's arsenals, including increasing its collection of mid-sized drones, obtaining large numbers of precision-guided missiles from the US and purchasing additional air defence batteries. Against the high trajectory threat Israel aims to both further enhance its multi-layered defence capabilities as well as prevent an enemy from firing. The guiding principle is to shorten the time of a conflict at a lower cost for the IDF and Israeli civilians and defending the country against both state and non-state enemy armies. This requires the military to have at ready a concrete list of targets, the weapons needed to hit them and the ability to do so rapidly. In order to do so,

[26] The Belfer Center translated the Hebrew version of the IDF doctrine to English: (Belfer Center, 2015).

Momentum focuses on improving its military intelligence's ability to locate targets in enemy territory, outfitting troops from across the IDF with better and more weapons and equipment and focusing exercises on the type of fighting that soldiers are expected to experience. The use of technology, in this case primarily AI and big data, is expanded, to identify potential targets for military strikes. The IDF wants to maintain its 'qualitative military edge' to create a bigger gap between Israel and its enemies, by for example disrupting communication or resupply lines. According to Israel, the future of war will consist more of UAVs and precision-guided munitions (PGM), to improve accuracy, in combination with strong manoeuvre capabilities. The latest is partly enabled by Israel's cooperation with the US in the context of air defence and the F-35 fighter jet. It currently has two squadrons of F-35s (Hunter & Newdick, 2020). The next 30 F-35s are expected to be delivered by 2024. Another example are the developments to use AI and networked digitisation to bind units together and create force multipliers. Most of the changes under Momentum, including future combat vehicles using the latest AI technology (Carmel), are expected to take multiple years to become operational (Frantzman, Israel rolls out new wartime plan to reform armed forces, 2020).

5.2.3 Artificial Intelligence

In 2019, the director of DDR&D announced the 'Carmel' programme: the development of combat vehicles that are using the latest AI technology to identify threats, reduce collateral damage and enable the formations of manned and unmanned vehicles in theatre. They are all sharing information in real time. The challenge on the future battlefield for armoured vehicles is to be able to operate with agility and detect and identify threats, some of which might be hiding among civilians or in civilian homes. Technology being developed through Carmel aims to decrease the number of soldiers inside the vehicle from three to two, while enhancing mission performance. Its system uses the latest optics outside and screens inside to allow manoeuvrability and a 360-degree view. The programme has been realised by reaching out to the biggest defence industry companies (Elbit Systems, IAI and Rafael), letting them present ideas and carrying out trials (Frantzman, Israel's Carmel program: Envisioning, 2019).

The conflict with Hamas on the Gaza Strip in May this year was coined by Israeli officials as the first "artificial intelligence war". In the last couple of years, the IDF's Military Intelligence Unit has dedicated research to exploit AI in war, to predict enemy rocket launches, place, and time, helping soldiers on the ground to defend against them. In the latest operation against Hamas, the IDF used a multidisciplinary AI technological platform that centralises all data on terrorist groups in the Gaza Strip onto one system that enables the analysis and extraction of the intelligence. Intelligence officers created algorithms and code to develop several new programmes. 'Gospel' for example recommends officers of Military Intelligence 'quality targets' and sends them to the Israeli Air Force (IAF) to strike. Another example includes 'Alchemist', which uses AI and machine learning to alert troops in the field to possible attacks. Every unit commander in the field had the system with them on a tablet (Ahronheim, 2021). Although the vast amount of data was gathered during the last two years, the IDF Unit 9900's satellites were also used to detect changes in terrain (including missile launches) in real-time automatically.

Over the past two years, the IDF has been integrating facial recognition with a network of cameras and smartphones in the West bank. The smartphone technology ' Blue Wolf' takes photos of Palestinians, matches them to a database of images, which then tells the soldiers whether to detain the person or not. In addition, the IDF installed face-scanning cameras in Hebron to help soldiers identify Palestinians at checkpoints before they show their ID cards. A wider network of closed-circuit television cameras can provide real-time monitoring of the local population and even see into some private homes. It has been labelled 'Hebron Smart City' (Dwoskin, 2021).

This is closely related to one of the focus areas of Libertad: Smart City Tech (Mossad, sd). According to the IDF, Smart City projects aim to make urban living more sustainable (although in the above mentioned case, this obviously depends on who you ask) by researching possibilities for automation and digitising interactions between technologies, people and the physical environment. This is interesting for the security and defence field, since a great deal of future warfare will be focused on the networked urban environment (Kovalsky, Ross, & Lindsay, 2020).

5.2.4 Cyber & Electromagnetic Activities

Due to its innovative and well-funded tech industry in combination with its military environment, Israel is one of the most advanced cybersecurity and cyber-defence players in the world (Frei, 2020). The cybersecurity sector is rapidly growing as a sector. Cybersecurity software exports amount to $7 bn, are dominated by defensive technologies and represent 10% of the global market (Reuters, 2019). According to the Israeli National Cyber Directorate, the cybersecurity start-up market had already raised $3.4 bn in the first half of this year (exceeding last year's total sum of $2.9 bn). This figure accounts for 41% if the total funds that were raised by cybersecurity companies worldwide (Solomon, 2021).

Moreover, the IDF has prioritised expanding cyber and intelligence units above all others (Jager, 2021). Unit 8200 is the elite unit of the Military Intelligence Directorate and by now the biggest one within the entire IDF. Its soldiers oversee developing and utilising information gathering tools, analysing, processing and sharing of the gathered info to relevant officials (Israel Defense Forces, 2021). Graduates (mostly reserves) go on to launch successful start-ups, predominantly in cybersurveillance. A 2018 study estimated that 80% of the 2,300 people who founded Israel's 700 cybersecurity companies had come through IDF intelligence (Barshad, 2021). There is not a lot information to be found publicly on cyber innovations that the IDF or Unit 8200 specifically uses, but it is well known that the military establishment mingles closely with academia and business (Reed, 2015).

The NSO Group, a private company within the Israeli cyberweapons industry, is world-wide known for its Pegasus technology that can hack a phone without the target having to clink on a link. It was allegedly used by the Saudi government to hack the phone of a friend of Jamal Khashoggi's in order to monitor the journalist before his murder (Priest, Timberg, & Mekhennet, 2021). Similarly, the Israeli company Candiru sells software to states with which computers and cell phones can be hacked remotely. Although the software is said to be developed for governments and law enforcements agencies to fight terrorism and crime, the UN and Amnesty International have found the spyware on phones and computers of journalists, political dissidents and governmental critics (Marczak, Scott-Railton, Berdan, & Abdul Razzak, 2021). These companies are primary examples of the intertwinement of the Israelian military and the private sector, as veterans often continue to work in this sector.

The Israelian MoD regularly carries out cyber-attacks and does not always shy away from confirming it. In April this year, Israel seemed to have attacked Iran's main nuclear facility Natanz in response Iran speeding up the production of uranium. This attack can be placed in the context of a long-standing rivalry in the Middle East over amongst others Iran's nuclear programme. In 2010, the CIA and Mossad famously attacked Natanz with the Stuxnet-virus (Chulov, 2021).

Lastly, another one of the focus areas of Libertad Ventures seems interesting to explore further: Fintech (Mossad, sd). Fintech includes technological innovations in the financial sector, such as alternatives for banking and financial services and products. There are around 250 Israeli Fintech companies. (Israel Export Institute, sd) According to Start Up Nation Central, the Israeli Fintech industry has established itself as a frontrunner in financial innovation, which includes expertise in cross-over technologies like cybersecurity, big data analytics and AI. In July 2021, the organisation published a rapport stating that Israel's Fintech sector has experienced a record-breaking first half of 2021 in terms of Venture Capital investments. During this time, investments in Fintech made up 19% of the total funding in Israeli innovation technology companies. Over the last two years, 70% of Israeli Fintech funding was oriented towards three subsectors: payments, anti-fraud and Insurtech. This trend has continued in 2021, with payments claiming the first spot, comprising 35% of Fintech funding (Start-up Nation Central, sd). How can developments within the sector be used for military purposes? One example includes blockchain, which can prevent armed forces and their countries from cyber-attacks, defend critical weapon systems, manage automated systems, validate orders and information on the battlefield or manage supply chains and logistics. It would be even more powerful if it is combined with AI (Hashim, 2020).

5.2.5 Quantum

Last year, the head of quantum research of the DDR&D, Tal David, announced that the Israeli government approved $387.5 mln to invest in quantum research and capabilities and that a huge volume of quantum technology projects were moving forward. According to US defence reports in 2018 and 2019, quantum computers will transform the military area. It will not only have implications for decoding enemy communications and protecting internal communications but also for tracking stealth aircraft and anti-submarine warfare. David did not go into specifics but did mention that a large part of quantum's defence applications would be classified sensors (Bob, 2020).
There are also plans to cooperate with knowledge institutes. In 2019, Israel's Ben-Gurion University of the Negev announced intentions to pursue joint quantum research and development programmes with the IDF and US armed forces, together with other high-tech industry players both in Israel and abroad (Science Magazine, 2019).

5.2.6 Sensor

Last year, the IDF installed underground sensors along the border with Lebanon to be able to detect possible new subterranean tunnels. The sensor technology was installed a year after the Israeli defence forces discovered and destroyed such tunnels used by Hezbollah. The technology gathers acoustic and seismic data and is employed in a preventative fashion (Gross, IDF begins installing tunnel-detecting sensors along Lebanese border, 2020).

This year the DDR&D has announced a new technology centre with IAI, that is dedicated to the development of production of non-GPS navigation systems. IAI will develop and manufacture accurate inertial sensors to enable the production of next-generation navigation systems and increase their performance for modern battlefields (Spiro, 2021).

An innovation that the IDF specifically mentions as one of its top-10, is the “Eye-Ball”. This is a small black ball equipped with a camera with infrared capabilities that can be thrown into a building, stabilises and then transmits a 360-degree image of the room. This way the soldier can stay outside, but still fully know what is happening inside (Israel Defense Forces, 2022).

5.2.7 Man-machine integration

According to the State of the Nation Report 2019 of the Taub Center for Social Policy Studies in Israel, approximately 15% of Israeli jobs are at high risk because of automation. Especially less-educated and lower-wage population groups, including Arab Israeli, women and foreign workers from low-income countries, risk losing their jobs (Weiss A. , 2019). Deloitte identified three trends related to the future of work (FoW) in Israel, of which the first is the amalgamation of humans and machines. Survey results state that 69% of cognitive-aware businesses view the future workforce as augmented, meaning that many employees will either have new positions influenced by AI or will experience being augmented by cognitive technologies. The technologies that are mostly expected to drive this change in the work environment are: (1) machine learning (ML) and deep learning (DL), (2) natural language processing, (3) intelligent automation, (4) robotics, including Robotic Process Automation (RPA) and Fixed Movement Robotics (FMR), (5) analytics, (6) digital communities, and (7) virtual collaboration. The industry for employing these technologies at work is rapidly growing in the Israeli high-tech ecosystem and has raised over $1,2bn until 2019. Especially analytics and ML/DL dominate the Israeli market, as they represent over 50% of the FoW technologies from Israel (Epner & Balissa, 2019).

5.2.8 Weapons

A special division within the DDR&D, Israel’s Missile Defence Organisation (IMDO), is responsible for the development, management and improvement of Israel’s active defence systems. Together they form a multi-layered defence array (Israeli Ministry of Defense, sd). Israel is famous for the ‘Iron Dome’, its air defence system which has a range of up to 70 km. When an enemy launches a rocket, the radar station detects and tracks its course, and then immediately launches a missile to intercept and neutralise the enemy rocket before it causes damage to civilians or property (Missile Defense Project, 2021). Together with David’s Sling, Arrow-2 and Arrow-3, they form Israel’s missile defence architecture. David's Sling defends against short-range ballistic missiles, large-calibre rockets and cruise missiles, and occupies the middle tier (Missile Defense Project, 2021). It stands above the point-defence Iron Dome and upper-tier Arrow systems. Arrow-2 intercepts short- and medium-range ballistic missiles in the upper atmosphere (Missile Defense Project, 2021). Arrow-3 is designed to defend against medium-range missiles in space. It is the longest-range interceptor with the Arrow Weapon System and complements Arrow-2 (Missile Defense Project, 2021). Israel's missile defence systems are developed in cooperation with the US. In January 2022 the Arrow weapons system was (successfully) tested by sending two Arrow 3 interceptors at a target from the Negev desert (Weiss Y. , 2022).

Currently, IMDO and the US Missile Defence Agency are working together on the next-generation Arrow 4 air defence missile that would be able to counter new types of long-range missiles. It is suggested that this includes manoeuvrable hypersonic cruise missiles and glide vehicle type weapons as well as ballistic missiles that release multiple warheads; multiple re-entry vehicles (MRVs) or multiple independently targetable re-entry vehicles (MIRVs). However, these types of missiles are currently not yet operational in the Middle East (Roblin, Israel and U.S. To Develop New Arrow 4 Missile to Defeat Hypersonic Weapons, 2021). No indications have been found that Israel is developing hypersonic missiles itself. A recent report of the US Congressional Research Service has stated that Israel has conducted foundational research on hypersonic airflows and propulsion systems, but that the country is not pursuing hypersonic weapons capability at the moment (Sayler, Hypersonic Weapons: Background and Issues for Congress, 2021). Thus, the focus seems to be more on defence against hypersonic missiles.

To defend tanks from anti-tank missiles, Israel has developed the ‘Trophy system’ which creates a 360-degree protective shield around a tank. Similarly, to the Iron Dome, the system instantly detects and neutralises the threat by firing a missile of its own to explode the enemy missile. The “Merkava IV” tank includes a fire control system with the ability to defend against helicopter attacks, a digital battlefield management system, and an unprecedented suspension and tracking system that enables movement even on the roughest of terrains (Israel Defense Forces, 2022).

Israel has adapted the F-16 to the specific needs of the Israeli Air Force. The F-16I has been equipped with a state-of-the-art weapons system, a specially constructed radar system, and a unique helmet system that allows the pilot to launch weapons at an enemy plane using only sight (Israel Defense Forces, 2022).

The “Spike” is a rocket launcher that was developed specifically for the needs of the IDF. The newest edition features a 40% reduction of weight from its previous design. It mounts to the shoulder and is the first of its kind with unique characteristics better equipped for ground operations. The “Spike” can be transported quickly and easily and can reach structures accurately from hundreds of feet away (Israel Defense Forces, 2022).

The Israeli MoD announced a “breakthrough” in the development of laser technology in January 2020. The “new age of energy warfare” requires technology to intercept aerial threats, including drones, rockets, artillery, mortars and anti-tank guides missiles. The laser beam's power and accuracy were strengthened in other to target and stabilise the beam from a distance. The technology has the potential to provide a more cost-effective missile defence capability. However, the technical realities still have some limitations. Even though the laser beam can travel at the speed of light, which is much faster than traditional kinetic capabilities, it would need to remain on the target for some seconds before being able to destroy it.

While the Iron Dome can launch multiple inceptors simultaneously (to multiple targets), one laser can only hit a single target (Nagel, Bowman, & Zivitski, 2020). The current prediction is that the airborne laser weapon, developed in cooperation with Elbit Systems, has an operational prototype by 2025. It can then be incorporated in Israel's multi-tier air defences, including the Iron Dome system against short-range rockets and the David's Sling and Arrow systems against ballistic missiles (Reuters, 2021).

5.2.9 Space

Like its approach to the cyber industry, Israel seems wanting to position itself now as a space-technologies hub. However, the number of start-ups in the space industry are still relatively low. Based on Start Up Nation Central data, an independent research organisation, 62 space-tech companies are active in Israel, of which 40 were established between 2000 and 2021 (Ashkenazi, 2021).

Israel is one of 13 countries with satellite-launching capabilities. The DDR's Space Administration has a multi-year space and satellite development programme. Leading the way is the Ofek satellite series (Israeli Ministry of Defense, sd). In 2020, the Ofek 16 reconnaissance satellite was launched. According to Israel, the satellite will provide technological superiority and intelligence capabilities and together with the other satellites in orbit, they will give Israel a large coverage. The satellite was developed with the three largest defence companies of Israel: IAI, Elbit Systems and Rafael. Once operational, Ofek 16 will deliver images to the IDF's 9900 Intelligence Unit (Frantzman, Israel launches Ofek 16 satellite to complete intelligence coverage, 2020). Moreover, in March this year three autonomous nanosatellites were launched by Technion – the Israel Institute of Technology (Technion, 2021).

The Israeli space agency assisted with the founding of Ramon, a space computing company that builds computer systems adapted to the extreme conditions of space, which can process vast amounts of data. It also develops AI and signal processing-based components. The systems can be used for satellite communications, the observation of earth and remote-sensing satellites as well as data centres to be built in space and on the moon. Ramon's clients are international state space agencies and private companies. In a recent interview, the CEO of Ramon stated that the field of space services and applications is still in its infancy, but that the Israeli start-up industry facilitates a fruitful environment for space innovation (Kogosowski, 2021).

Other noteworthy companies include Helios, Oneview and Effective Space. Helios intends to develop a system to produce oxygen from lunar and Martian soil, allowing future space launches to reduce the thousands of tons of the vital gas they currently carry. Oneview provides a platform for the creation of synthetic datasets for the analysis of earth observation imagery by ML algorithms. ML models perform better when they are fed by more data. However, geospatial data can be expensive, preparing it for processing manually is time-consuming, and its coverage limited. Oneview aims to optimise this. Lastly, Effective Space develops space drones that provide maintenance and extend the life cycle of satellites in orbit (Ashkenazi, 2021).

5.2.10 3D printing and new materials

The IAF uses 3D-printing technology to print munitions, tools and replacement parts for aircrafts. Its Aerial Maintenance Unit is also employing 3D-scanning techniques to scan an object and turn it into a computerised model, making the printing process independent of human performance. The scanner can also be used after printing, to compare the computerised model and its printed version to each other (Pe'ery, 2019).

The Israeli MoD and Israel Aerospace Industries (IAI) produced the country's first 3D-printed UAV. The joint program by the MoD's Flight Technologies Department, part of the DD&RD, and IAI has seen the production of the SkySprinter UAV and a successful test flight in December 2019. The electrically powered UAV was made from 26 parts printed using metal, nylon, carbon, and complex materials. These were assembled with glue and fasteners without the need for specialised tools. The printing technique known as selective laser sintering (SLS) allows new designs of the SkySprinter to be rapidly produced in line with operational feedback from commanders on the ground. SLS technology solidifies polymer materials in precise measurements to produce finalised parts (Lappin, Israel's first 3D-printed UAV takes to the skies, 2020).

This year, the MoD and Polaris Solutions, an Israel-based survivability technology company, invented a new material matrix that can hide soldiers from infrared sensors, making them more difficult to detect. The new camouflage technology, Kit 300, is made of thermal visual concealment material that combines metals, microfibres, and polymers that makes soldiers virtually "invisible" (Zitser, 2021).

5.2.11 Biotechnology

Bio or health tech is an increasingly popular industry for the plethora of Israel start-ups. According to a report from Israel Advanced Technology Industries, an umbrella organisation that represents Israel's life science and hi-tech environment, biotechnology represents one quarter of Israel's life science scene. This includes 468 active biotech firms. A lot of these innovations are linked to agrotech, especially since agriculture is an important income source for Israel (Israel Export Institute, sd). Also, the Israeli government is investing in 'bio-convergence', which refers to research combining biology with computer engineering, big data, AI and advanced manufacturing (IATI - Israel Advanced Technology Industries, 2021). In 2020, the Israel Innovation Authority approved the establishment of the CRISPR-IL27 consortium, that integrates AI and CRIPR technologies to develop computational tools for genome editing (Pick, 2020). Other examples include 3D printing of human tissue and organs and nano-robots for delivering medicine inside the body.

Still, according to Start Up Nation Central, pharma start-ups only raised $291 mln and digital medical firms $836 mln from investors in 2019 – which pales in comparison to the cybersecurity start-ups that took in $1.6 bn that year (Start-Up Nation Central, sd). Similar trends are demonstrated in the figures for sales of tech firms (2.3 bn for biotechnology and 8.2 bn for software and information technology) as well as the salaries (Cohen, 2020).

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[27] Clustered Regularly Interspaced Short Palindromic Repeats – or repetitive DNA sequences. It is a technology that is used for editing genomes.

Nonetheless, like the trend of veteran intelligence professionals moving on to the private cybersecurity sector, a part of them is now interested in biotechnology sector. One example is the launch of Smashing DNA, a programme that gives graduates of the cybersecurity units the tools and knowledge to work in biotech, health-tech and computational biology. Also, the public benefit company 8400 aids alumni of army intelligence units to form health tech communities with its Spearhealth programme (Cohen, 2020).

5.2.12 Simulation and virtualisation

The Israeli firm Rafael Advanced Defence Systems has produced digital battlefield technology, in which Germany and the US have shown interest. The Fire Weaver is an advanced, augmented-reality system that connects all friendly forces to a single battlefield picture and makes sure that all of them are looking at the exact same targets. Developed in close cooperation with the IDF, the Fire Weaver can shorten the sensor-to-shooter cycle. It turns all the forces in each area into a single digital network, able to detect and instantly share targets with one another (Lappin, Israel's Rafael reshapes urban-warfare with AI, augmented reality, 2020).

Also Israeli firm Elbit develops advanced simulation solutions, ranging from individual soldier to full-scale joint forces LVC training systems, and modeling, visualization and networking capabilities. In 2020 the IDF initiated a series of brigade level exercises in Elbit Systems' new Brigade and Battlegroup Mission Training Center (B2MTC). The new training center immerses commanders, headquarters staff and two subordinate command levels in high-fidelity combat situations in actual battle zone territory. B2MTC presents commanders and their staff with a realistic operational picture, enables them to operate a range of assets, compels them to respond to real-time changes and requires them to cope with tactical communications that are realistically impacted by various effects (Elbit Systems, 2020).

5.2.13 Human Performance and Training

Most of the technology and innovations found in open sources relate to training. Nothing specifically was found on improving physical, cognitive and mental military performance, although it is very likely that Israel is running programs in this area.

In 2017, the IDF revealed the Snir facility, which is a new training facility in the Golan Heights that is meant to simulate a Lebanese village so that Israeli soldiers can practise urban combat. Unlike the previous established Urban Combat Centre, the Snir facility is also designed for heavy tanks and engineering vehicles to enter the mock village. Moreover, it includes underground elements since adversaries like Hezbollah are known for subterranean bunkers and tunnels (Gross, With eyes to Hezbollah, IDF unveils 'Lebanese village' training cente, 2017). Similarly, in 2020, the IDF opened another combat training facility near the Lebanese border, to mock the exact conditions of combat in Lebanon. It was decided to be build, based on lessons learnt from an incident in 2019 in which Hezbollah fired a Kornet missile that narrowly missed an IDF vehicle. The IDF is following the changes that Hezbollah and the northern border are undergoing and aims to stay ahead of them (Lappin, IDF opens new combat training facility on Lebanese border, 2020). The multi-year strategic plan 'Momentum' also states that the IDF will focus its training exercises more heavily towards urban combat, as it believes that soldiers are more likely to fight in cities and towns than in the open fields where many drills are currently held (Lappin, The IDF's Momentum Plan Aims to Create a New Type of War Machine, 2020).

Another way in which the IDF is exercising in mock Lebanese villages, is through a virtual battlefield centre. The advantage is that the officers can train without using field resources. The system documents field failures and virtual casualties, that help units learn from their mistakes. The centre is an example of the growing focus on digitisation as stated in Momentum, including giving more tools to the IDF such as networked technology. The B2MTC virtual stimulator was developed by Elbit Systems. Elbit has also been working with the Royal Netherlands Army simulation centre (Frantzman, Israel increases training via virtual battlefield center amid Hezbollah tensions, 2020).

5.2.14 Robotics and Autonomous systems

It is fair to state that Israel is one of the world's largest UAV users and manufacturers. In 2017, an estimation was made that Israel's export of (unarmed) UAVs was over 60% of the global market over the previous three decades, and that the country had delivered 165 UAV units to foreign buyers (Catalano Ewers, Fish, Horowitz, Sander, & Scharre, 2017).

At the beginning of de 21st century the IDF created two secretive units within the artillery corps to train for a more urban battlefield. Instead of artillery weapons, the units were equipped with UAVs to conduct assault and reconnaissance missions. The assault UAV unit (Zik or Unit 5252) operates the Hermes 450 UAV. This is a multirole, high-performance, tactical UAV that can collect intelligence, conduct electronic warfare and launch missiles. The added value of the Zik unit is their ability to use precision-guided munitions to launch surgical strikes, which threaten distant and hidden targets, while minimising collateral damage (Rokani, 2021). Moreover, the UAV unit tasked with reconnaissance (Sky Rider of Unit 5353) operates the Skylark I, II and III (Efrat, 2011). This UAV is miniature, modular, light and almost undetectable. It can be packed up by ground forces and deployed within 8 minutes. The Skylark can fly for three hours while passing life, high-resolution videos in day and night and any weather condition (Israel Defense Forces, 2022). The Sky Rider unit is primarily there to deliver real-time, tactical intelligence to combat officers on the battlefield.

Other UAVs that are currently employed by the IDF ground and naval forces are the Eitan (Heron TP), Shoval (Heron 1) and Hermes 900. The Eitan for example has a different function from the previously mentioned UAVs. It has a wingspan of a little over 25 meters and can carry out long-range missions for 36 hours life in the air. It can also operate under any weather condition. It is equipped with an automatic defrosting system, a take-off and landing system, and can be integrated with many sensors (Israel Defense Forces, 2022).

The IDF also deploys unmanned ground vehicles. Currently, they are using the Jaguar, which was developed in cooperation with IAI, to patrol the border with the Gaza Strip. It is one of the first robots in the world that can operate autonomously, although weapon stations are still controlled via a human in the loop from the control centre (Papadopoulos, 2021). It can operate 24 hours, 7 days a week and is equipped with a machine gun and aids in reducing the troops exposure to the dangers of border patrols (Israel Defense Force, 2021). In September this year IAI presented a four-wheel-drive robot, REX MKII, which is operated by an electronic tablet and can be equipped with two machine guns, cameras and sensors. The UGV can be used to gather intelligence for ground troops, carry injured soldiers and supplies and attack nearby targets. Moreover, it gathers data and learns from it for future missions (Times of Israel, 2021).

One of the first cooperation projects that was made public after the signing of the Abraham Accords[28], is between the United Arab Emirates (UAE) defence organisation EDGE and the Israeli IAI to jointly design unmanned vessels that would be capable of semi and fully autonomously carrying out submarine detection and anti-submarine warfare: The 170 M. It could also be used for ISR, mine detection and sweeping, and as a deployment platform for certain types of aircraft. In de civilian domain, the vessels could be deployed for oil and gas exploration (Al Jazeera, 2021).

Another interesting development last year, was the use of swarm technology in the Gaza war. It was dubbed by the Israel MoD as the combat debut of a new IDF capability that demonstrated the great value of manned-unmanned operations at the tactical edge. The arrival of the AI-driven drone swarms can be linked to the new Momentum plan that focuses on technology and modernisation, including the creation of a new multidimensional group of units. One of the main tools used is Elbit’s Digital Army 750 system, which will be more explained in the next section (Frantzman, Israel is leading the way as drone swarms come to the Middle East, 2021).

5.2.15 *ICT and networks*

Rafael Advanced Defence Systems produced a software called BNET. The BNET family of software defined radio (SDR) systems provide a robust voice and data-link solution and support simultaneous data, voice and video services with multiple auto relays. The system is operational and combat-proven with several air forces around the world and features a unique software-defined radio and network architecture, delivering wideband communications with low delay and reliable connectivity. One variant is the BNET-AR, a modular multiband SDR for airborne platforms, integrated onboard fighters and helicopters as well as in ground control stations, enabling net-centric operations and real-time situation awareness. BNET is a spectrum aware SDR utilising the spectral arena of the battlefield to the fullest in a cognitive way, thus addressing the challenges of the modern battlefield such as limited spectrum and the connection of multiple sensors and shooters. All this is achieved by BNET's Multi-Channel Reception (MCR) technology that enables it to receive and analyse information from numerous frequency channels simultaneously using a single RF head (IsraelDefense, 2021). India has procured the BNET Software to use on all its combat aircrafts (The Shephard News Team, 2021).

As part of the IDF’s digital transformation, it carried out a digital situation assessment. On division level, staff officers can now share a joint situation picture and conduct situation assessments on ICT tools. This capability is delivered by Elbit’s Digital Army Programme (TORCH 750), the main C4ISR system of the IDF. By increasing bandwidth during the operation, the combat management system can

[28] A joint statement between Israel, the UAE, Bahrain and the US to start cooperating more in amongst other security, economics and culture. This normalisation has created opportunities for Israel to engage with the Arab world (Lynfield, 2022).

provide a real-time picture of blue (friendly) and red (hostile forces), and link ground forces to the Israeli Air Force and Navy. The device integrates data from the three IDF branches, creating a network for the multi-domain battlefield (Eshel, 2021).

5.2.16 Behavioural engineering

The information that was found in relation to behavioural engineering, was focused on influencing (the behaviour of) populations. The use of facial recognition technology as a part of profiling efforts can be found in the AI section. Other psychological operations developments within the military context are difficult to gather via open source information.

The conflict between Israel and Palestine has witnessed a lot of disinformation efforts. The BBC researched examples from both sides, in which also the spokesperson for former Israeli Prime Minister Benjamin Netanyahu shared a video on Twitter, claiming that it showed footage from Palestinian militants launching rocket attacks on Israel in Gaza. However, the video was outdated and was from Syria. The same is happening at the other side, by for example sharing fake Twitter posts from the IDF (BBC Monitoring, 2021). After each moment of heightened violence in the region, disinformation like this is widely shared on social media (Frenkel, 2021).

In May this year, the IDF was accused of misleading international news outlets to lure Palestinian militants into positions that made them targets for Israeli airpower. The IDF shared a statement with news reporters that they were gathering along the border with Gaza, which prompted the enemy fighters to go into their tunnel system to prepare for combat. When that happened, the IDF flew over and attacked the so-called ‘Gaza metro’ network. Moreover, at that point the IDF withdrew their earlier statement to the reporters, which led them to speculate that this was all a part of a disinformation strategy (Kossoff, 2021).

5.2.17 Energy

At the virtual climate convention in April 2021, former Israeli Prime Minister Benjamin Netanyahu recalled the government's goal of generating 30% of electricity from renewable sources by the end of this decade. Another goal is to become a net zero carbon economy by 2050 (Della Ragione, 2021). Israel is currently in dialogue with Egypt to build solar power plants in the neighbouring country as well as in Jordan. If Egypt and Jordan have enough open land to be used for these plants, Israel will provide the technology. Most of the energy will be re-supplied to Israel to help achieve its electricity targets (Egypt Independent, 2021). The head of Israel’s Energy Ministry planning unit is drafting a policy plan regarding dual-use solar energy sites. This includes army bases and putting solar panels above army firing ranges and cleared minefields (Surkes, 2021).

5.3 Official sources

The table below shows a shortlist of the main official policy documents and sources that have been consulted.

Title	Comments	References
MoD website	Provides an overview of organisation and ambitions	https://english.mod.gov.il
IDF doctrine (translation by The Belfer Center)	Describes the 'strategy document' of the IDF	https://www.belfercenter.org/israel-defence-forces-strategy-document.
Momentum or 'Tnufa' in Hebrew	IDF strategy: a multi-year plan to transform its armed forces	https://www.idf.il/en/minisites/dado-center/vol-28-30-military-superiority-and-the-momentum-multi-year-plan/multi-year-plan-momentum-a-theoretical-framework/

6 Russia

6.1 Overview benchmark results

6.1.1 General data and assessment results

The table below presents key data that reflect Russia's geopolitical challenges and drivers as well as its strengths and general facts relevant to the defence and security environment.

RUSSIA: GENERAL INFORMATION	
Geopolitical challenges and drivers	• Desire to be acknowledged as a great power • Perceived geographical and military isolation by NATO on its Western flank • Strongly reliant on energy (mostly to Europe) as well as weapon exports for its economy. • Economic decline • Waning domestic political support (The Economist, 2021) (Center for Strategic & International Studies, 2021) (Wizevich, 2021)
Strengths	• Nuclear weapons • Large arsenal of military equipment (Global Firepower, 2021) • Strongest tank and artillery forces globally, and global top player in naval force and in air force • Second largest exporter of military hardware
Defence budget [2020]	• $61,7 bn (4,3% of GDP) (SIPRI, sd) • $423 per capita • 11,4% of total government spending
Defence size [2020]	• 1,014 mln active personnel (Global Firepower, 2021)
R&T budget [2018]	• Approximations differ between 11,5% (Engvall, 2021) and 24% of state defence budget (Davis, 2021)
Research & Technology partner countries	• Most prominent partners: China and India (Jankowski, 2021)
Arms industries	• Rostec, Almaz-Antey, Roscosmos, Tactical Missiles Corp., United Shipbuilding Corp., United Aircraft Corp., Rosatom (Crane, Oliker, & Nichiporuk, 2019) (Bowen, 2021)
Arms export [to]	• India, China, Algeria (Wezeman, Kuimova, & Wezeman, 2021)
Arms import [from]	• Ukraine

The following table provides a summary of the key findings for each of the 15 SKIA technology areas. The column 'Focus' indicates the level of priority the referent country gives the respective technology area vis-à-vis other technology areas: high (+), moderate (0) or low (-). This reflects the governmental attention, based on policies, plans and investments, as well as concrete activities in research, technology and innovation. Also, it demonstrates the level of technological development that one can expect from a powerful military player.

RUSSIA: TECHNOLOGY AREAS			
	Technology Areas	**Focus (+,0,-)**	**Findings**
1	Artificial Intelligence	0/+	• Strong interest in using AI applications in both the military and civilian domains. • High reliance on foreign markets for expertise and materials essential to AI applications, further impeded by sanctions.
2	Cyber & Electromagnetic Activities	+	• Russia perceives CEMA/EW as a central component to warfare; vast arsenal of various EW capabilities • C2 Disorganisation (C2D) will create a heavily CEMA-denied environment in combat operations.
3	Quantum	0	• Russia lags 5-10 years behind the US and China in its quantum research. • Russia is investing $790 mln between 2019 and 2024
4	Sensor	-/0	• Sensors are a notably weak component of the Russian armed forces, relative to their other systems. • Russia prefers mass as an effector multiplier above precision strikes.
5	Man Machine Integration	0/+	• Limited information on military MMI • Advanced stage in man-machine integration, in line with US and China.
6	Weapons	+	• Russia has a wide range of legacy and novel/high-end weapon systems, the latter also in development. • The Avangard Hypersonic missile able to circumvent most of NATO Air & Missile Defence systems. • Globally strongest land forces, equipped with legacy Soviet artillery and manoeuvre systems, upgraded with novel components.
7	Space	+	• Russia has developed its own Global Navigation Satellite System (GNSS), named GLONASS. • Russia is catching up on SAR[29], enabling all-weather high-resolution land observing/monitoring capability. • Russian has Anti-Satellite (ASAT) weapons capability.
8	3D printing & Materials	0	• First Additive Technologies Centre opened in 2021. • Likely intended to produce components for legacy systems upgrades.
9	Biotechnology	0/+	• Russia is pursuing a whole-of-government approach to boost its biotech research. • Suspected intentions of dual-use capability
10	Simulation & virtualisation	0	• Russia has demonstrated a new virtual weapons simulation environment with the Spektr-7E in 2019. • Simulation technologies to be used for training of the armed forces.
11	Human Performance & Training	0/+	• Development of Human Performance Enhancement, including Brain-Computer Interface technologies.
12	Robotics & Autonomous systems	+	• Intention to have 30% of the armed forces consist of unmanned systems. • Russia has acquired multiple class I UAS, particularly for ISR and artillery spotting capabilities. • Russia is continuing its swarming research, with a focus on ‘hybrid’ swarming architectures.
13	ICT & networks	0	• Attempts to simplify and digitalise its C2 systems. • Policy documents do not offer solutions to resolve interoperability problems. • Intention to have 40% of ground forces network-enabled, and 100% of special forces by 2030.

[29] Synthetic Aperture Radar.

RUSSIA: TECHNOLOGY AREAS		
Technology Areas	**Focus (+,0,-)**	**Findings**
14 Behavioural engineering	+	• Extensive use of behavioural engineering, e.g. Russian election interference • AI-enabled Generative Adversarial Networks research will improve the quality and quantity of dis- and misinformation production and dissemination.
15 Energy	-	• National Energy Strategy to rely on fossil fuels, ambition to become a hydrogen exporter by 2050. • No information retrieved about energy transition in the military, likely no main goal

6.1.2 *Takeaway's*

The key takeaway's for the assessment of Russia's ambitions and activities on military science and technology are:

- Russia's main driver to modernise its armed forces, is to close the capability gaps with its strategic rivals: the US, NATO and China.
- This is done through a combination of buying completely new systems on the one hand (although limited), and upgrading existing old ones on the other hand, especially in relation to its artillery and manoeuvre forces, resulting in a 'repair-and-upgrade' together with a 'retain-and-adapt' approach to military innovation.
- High focus on C2 Disorganisation (C2D), to create a heavily CEMA-denied environment in combat operations, and behavioural engineering, including using AI-enabled technology. Also, Russian has achieved an Anti-Satellite (ASAT) weapons capability.
- One (sub)technology area was identified that is currently missing in the SKIA: Smart City Tech, which is said to leverage the uses of AI for the benefit of the public and private sectors in collecting and using big data.

6.2 Benchmark analysis

This subchapter presents the actual benchmark analysis upon which the table above and the key takeaways are based. It starts with an introduction, after which it zooms in on Russia's research, technology and development base in general. Following, it analyses each technology area more in-depth. It ends with a concise table with the most important official sources used.

6.2.1 *Introduction*

It is important to Russia to modernise its armed forces, because of the ongoing state of conflict it perceives itself to be in with powerful competitors: historically the US and NATO, and increasingly China (Bendett, et al., 2021). It is a priority for the Kremlin to pursue the development of advanced military technology to defend itself. The increased attention to modernise its defence systems started with the 'New Look' reform programme, that the former Minister of Defence, Anatoliy Serdyukov, initiated in 2008. In 2020, the current procurement cycle started that will guide the modernisation of the Russian armed forces until 2027 (GPV 2027) (Connolly & Boulègue, 2018). It is expected that the items procured under GPV 2027 will be more balanced across all branches of the armed forces, with a focus on force-multiplier technology and asymmetric capabilities. The main goal for Russia is to close the capability gaps with its strategic rivals (Zysk, 2021).

Characteristic of the Russian innovation process is the combination of procuring new systems and improving old ones. The Russian military-industrial complex (which is referred to as ‘OPK’ in Russian) is limited in its ability to produce entirely new systems. This impacts the Russian military R&D sector, resulting in a ‘repair-and-upgrade’ together with a ‘retain-and-adapt’ approach to military innovation (Bendett, et al., 2021).

Besides Russia’s threat perceptions, its military innovation is driven by lessons learned in recent operational experiences attained in both Syria since 2015 and Ukraine since 2014. The Russian armed forces used these deployments as an opportunity to test new and experimental systems to close the gap with its counterparts, which was particularly useful for C2 systems, unmanned capabilities, electronic warfare (EW) and precision-guided munitions (Clark, 2021).

The Russian military innovation model is thus driven by both its foreign policy perceptions and goals, as well as lessons learned in theoretical research and operational experiences. In addition, it is quite traditional, driven by the state in a top-down manner and is characterised by incremental change (Zysk, 2021). However, more synergies are increasingly created between the military and the civilian sector, to make use of the progress made in the civilian (commercial) industry (Bendett, et al., 2021).

6.2.2 Research, Technology and Development in general

After a rise in governmental spending on military R&D, it plateaued at the beginning of the 2020s. It is unclear whether the current and future level of funding will be enough to finance the ambitious goals in the technological domain. Most likely, the biggest challenge for the defence industry will be the decreasing amount of state contracts with output for the civilian market. The official defence-industrial strategy for the 2020s states that it wants the defence industry to convert 30 % of its output to civilian and dual-use products by 2025, and 50 % by 2030 (Engvall, 2021).

In addition to its ministries, Russia’s military R&D infrastructure mainly consists of three types of organisations: research institutes (applied defence research), design bureaus (development of prototypes) and scientific production associations (combination of R&D facilities with production factories) (Engvall, 2021). Overall, it is comprised of approximately 600 organisations. The most important ones are outlined below.

Because of the history of privatisation since the dissolution of the Soviet Union, after which Putin renationalised many industries (including defence), many sectors are actually state-controlled through the form of vertically integrated holding companies. Such a holding brings together many connected enterprises. At the top of the pyramid is the state holding corporation Rostec, which controls most of the largest Russian defence industry corporations. This includes amongst others United Aircraft Corporation, Kalashnikov, Uralvagonzavod, Russian Helicopters and High Precision Systems. Overall, Rostec controls more than 800 companies, which are consolidated into 15 holdings (Engvall, 2021).

<u>GUNID</u>

Russian MoD has a Main Directorate of Research and Technological Support of Advanced Technologies (Innovative Research) (GUNID). The goal of GUNID is to organise and support the development and implementation of advanced R&D programmes and scientific projects, and to facilitate favourable conditions to create advanced weapons, and other (special) equipment. The focus on innovation is relatively new and resulted in some unfortunate decisions in the past, whereby the needs of the armed forces were neglected. To improve the innovation process, the current head of GUNID, Major-General Andrey Goncharov, states that the Directorate has established cooperation and communication channels with the military commands to collect information on their specific requirements. Now GUNID employees take part in military exercises to test different sorts of equipment. Another duty of GUNID is to monitor and document innovative technologies, in Russia as well as abroad (Bendett, et al., 2021).

<u>Civil-military technology innovation centres</u>
Several scientific innovation centres were created to create more synergy between the civilian and the military sector, by bringing scientists (theory) and practitioners (operational experience) together. The government formed the Advanced Research Foundation (ARF) in 2012 to develop civil and dual-use technologies (in 2020 it was implementing 40 innovation projects), and the Era technopolis (technology campus) emerged in 2018 to explicitly focus on technology for the armed forces. Era is managed by a council supervised by Deputy Prime Minister and former deputy minister of defence Yuriy Borisov (Bendett, et al., 2021).

The programmes of ARF are primarily centred around:
- 4IR technologies, with a high priority on AI and a focus on unmanned vehicles (e.g. Marker UGV);
- Autonomous systems and automated decision-making;
- Superconductors (Liman);
- Additive technology of polymetallic products (Matritsa);
- Full-ocean depth autonomous deep-submergence vehicle (Vityaz’-D);
- Ultra-thin materials for improving individual camouflage and protection (Tavolga).

Era’s R&D is organised in 14 fields:
- AI;
- small spacecraft;
- robotics;
- information security;
- automated control systems and IT systems;
- power-supply technologies and life-support machines;
- technical vision and pattern recognition;
- informatics and computer engineering;
- biotechnical systems and technologies;
- nanotechnology and nanomaterials;
- hydrometeorological (meteorological) and geophysical support;
- hydroacoustic object detection systems;
- military geoinformation platforms;
- weapons based on new physical principles.

When the Russian defence ministry assessed the research results in 2019, some of the more prominent involved telemedicine, AI for diagnostic systems, artificial neural networks, technical vision and autonomous control of UAVs (Bendett, et al., 2021).

The so-called 'bank of ideas' of Era is planned to be operationalised in joint projects, in which more than 100 enterprises of the military-industrial complex will participate together with representatives of Russia's main weapons manufacturers. The list includes amongst others the Kalashnikov concern (the country's largest producer of small arms, guided artillery shells and high-precision weapons), the Sozvezdie concern (the country's leading developer and manufacturer of EW and counter-EW systems), but also organisations like the Hevel Group (the largest cells-to-module photovoltaic manufacturer in Europe) and the cybersecurity company Rostelecom-Solar (Bendett, et al., 2021).

In addition, the Russian Ministry of Defence has relocated some of its scientific units to Era. Since March 2021, eight scientific military units have been working within the above-mentioned R&D fields of Era, while at the same time they have been supporting specialist units of the armed forces, including the Aerospace Forces, the 12th Main Directorate of the Russian defence ministry, the Military Topographic Directorate of the General Staff, the Hydrometeorological Service of the Russian Armed Forces, and the defence ministry's Main Directorate of Research and Technological Support of Advanced Technologies (Innovative Research) (GUNID).

The Russian MoD has been pushing Era to collaborate with universities and research institutes, including the country's largest interdisciplinary laboratory, the Kurchatov Institute. It researches amongst others: next-generation nuclear power, information technology (IT), nanotechnology, biotechnology and cognitive technology.

Because the Russian military industry lacks professional expertise, the scientific companies that are connected to Era provide a base for training new defence professionals. Often, former military servicemen that were part of the scientific units, continue to work in the field by for example starting at one of the Era companies. Although this development helps the military industry, it is not enough to overcome the systemic problems involving amongst others: low productivity of labour, corruption, political pressure, the weak rule of law, the poor enforcement of intellectual property rights, heavy bureaucratic control, and poor development trends in education that do not provide a solid basis for high-tech development (Bendett, et al., 2021).

<u>Limitations to Russian Research and Development efforts</u>
Whilst Russia has pushed to restructure its military Research and Development programmes, it is still lagging behind the United States' and China's similar efforts to develop Emerging and Disruptive Technologies (Gokhberg, Sokolov, & Chulok, 2017). Russia is not as capable to leverage its interests in EDTs both from an economic investment perspective, as well as its possible applications within the military domain. In addition there are three structural constraints that severely limit the Russian potential to bridge the gap of R&D efforts compared to China and the US: 1) Russia tends to rely on domestic supply chains, which limits the potential of leveraging knowledge and innovation from countries and markets abroad. It has chosen to do so willingly, out of a fear of becoming too reliant on foreign

manufacturers for advanced technological applications; 2) Educational standards, especially in relation to science and engineering have declined. This is also reflected in the drop of Moscow State University's – a leading Russian computer science research institution – standing in global rankings (OECD, 2019). The development is closely related to the so-called 'brain drain', as IT experts migrate to work in other countries (Edmonds, et al., 2021). 3) Sanctions targeting Russia restrict its access to international expertise on and markets to international technologies, especially since the expansion of sanctions in response to Russian aggression towards Ukraine and the 2014 illegal annexation of Crimea (Jankowski, 2021).

Whereas the West has adopted or is working on various principles and frameworks on the ethical and moral uses of EDTs, both for general societal use, as well as for the Armed Forces, Russia has not included such elements in its military strategies for the development of EDTs (Bendett, Here's How the Russian Military Is Organizing to Develop AI, 2018).The Russian Federation perceives ethical and moral regulations on the research, development, and implementation of EDTs to hamper their efforts in technological races (Jankowski, 2021).

6.2.3 Artificial Intelligence

The Russian Federation has put a lot of faith in AI applications for the military domain to improve the Russian armed forces. In particular, the Russians see potential military benefits in AI applications for the modernisation of communications equipment, EW systems, robotics, and unmanned systems (McDermott R. , Shoigu's Image of Russia's Armed Forces: Mobile, Modern and Efficient, 2020). Russia published an AI roadmap in 2019 which outlined the relevant AI sub-technologies (Ministry of Economic Development (MoED) of the Russian Federation, 2019):

- Computer vision;
- Natural Language Processing;
- Speech recognition and synthesis;
- Intelligent decision-support systems;
- Promising AI techniques.

Russia also published its national strategy for the development of AI up to the year 2030 (Office of the President of the Russian Federation, 2019). This includes the following objectives:

- Support for scientific research in order to ensure the advanced development of AI;
- The development and evolution of software that uses AI technologies;
- Increasing the availability and quality of the data needed for the development of AI technologies;
- Increasing the availability of hardware necessary to solve problems in the field of AI;
- Increasing the extent to which the Russian AI technology market is provided with qualified personnel and the extent to which the public is informed about potential areas of application of these technologies;
- The creation of an integrated system for regulating the social relations arising in line with the development and use of artificial intelligence technologies.

In October 2021, the Russian government launched a Centre for the Fourth Industrial Revolution in Russia (Russian Government, 2021). It signed a memorandum with the World Economic Forum (WEF) to help facilitate the implementation of the WEF's global projects in Russia. The three focal points for the Centre are: 1) IoT, with a particular focus on the digitalisation of the economy; 2) Robotics, including research, concept development, and regulatory frameworks; and 3) Smart City, to leverage the uses of AI for the benefit of the public and private sectors in collecting and using big data.

As enthusiastic as Russia was, as sceptical are Western observers about the potential of AI applications for the Russian military. Russia's private AI sector is small, and unable to retain its talent (Dear, 2019). In addition, Russia is highly reliant on foreign markets for the knowledge and material necessary for AI applications, like semiconductors and micro-electronics (Bendett, et al., 2021). Sanctions following the Russian illegal annexation of Crimea has further impeded such access to high-end technologies. Specific AI applications are addressed in the various, relevant sections.

6.2.4 Cyber & Electromagnetic Activities

The Russian military has heavily invested in novel Cyber and Electromagnetic Activities (CEMA) capabilities. Its investments are focused on fitting into its Anti-Access/Area Denial (A2/AD) approach and is tailored to targeting NATO C4ISR systems (McDermott R. , 2017). Russia wants to use CEMA capabilities in its EW approach of Command and Control Disorganisation (C2D) (Thomas T. , 2019). The focus of EW is in this case on disrupting, slowing, or destroying NATO C2 nodes which would slow logistics support, the tempo of advance and overall effectiveness of troops. Such disorganisation in the adversary's camp would give Russia the advantage and would enable them to attain A2AD superiority.

EW brigades have been stationed in all of the Russian Military Districts since 2016, a clear indicator of the importance Russia puts on the role of EW in operations (Kjellén, 2018). These brigades have been equipped with a variety of EW systems with novel jamming and spoofing capabilities. Such systems include the Krasukha-4, a road-mobile radar-jamming system that can provide protection against radio-locating surveillance satellites, ground-based radars, and Airborne Warning and Control Systems (AWACS) (MVR Simulation, sd); the Palantin, a road-mobile radio communications jamming system able to disrupt short-wave and ultra-short wave frequencies, and suppressing cellular communications in a reported radius of 1.000km (Cranny-Evans, 2019); The Murmansk-BN, a road-mobile system specifically designed to disrupt the US High Frequency Global Communications System (HFGCS) that is used to broadcast communications amongst NATO forces (Planesandstuff, 2019); the Tirada-2, a road-mobile system designed to jam communications satellites (Hendrickx, Russia gears up for electronic warfare in space (part 1), 2020); and the Leer-3, a road-mobile system with a GSM communications network monitoring, jamming, and spoofing system that works in conjunction with the Russian Orlan-10 UAS (Malyasov, 2016).

The systems described above are merely a small selection of the various capacities that the Russian Federation has acquired over the last decade. Given its emphasis on EW capabilities in its military procurements, and its vast testing of such systems in both the Donbass and Syria, it can be expected that any armed forces facing the Russian military will face a heavily electronics-denied environment in combat.

6.2.5 *Quantum*

According to several analysts, Russia likely lags 5 to 10 years behind in quantum computing technology, compared to global frontrunners the US and China (Schiermeier, 2019) (Thiele, 2020). To try and close this gap, Russia announced a plan to invest $790 mln in relevant research for the next five years and in addition implemented a five-year 'Russian Quantum Technologies Roadmap' in 2019. These developments are however not specifically related to the military domain, on which only limited information is available (Sayler, Emerging Military Technologies: Background and Issues for Congress, 2021).

6.2.6 *Sensor*

Russia has been a globally dominant power vis-à-vis its land forces, especially regarding their manoeuvre, and artillery capabilities. Through its operational testing of new concepts and systems, the Russian military has also encountered limitations to its military effectiveness. The Russian military is heavily reliant on ground-based sensors, which are a liability in expeditionary land operations. Whilst the computing revolution has enabled Russia to leverage the availability of commercially available hardware for its sensory capacities to augment its Soviet legacy tanks and artillery weapons systems – a central focus of Russian modernisation efforts in the last 20 years – the overall sensory capabilities of Russia remain lacklustre (Bitzinger & Popescu, 2017). Russia hopes to fill the gap of the limitations to its ground sensors by utilising air ISR capabilities, in particular through the development of small Unmanned Aerial Systems (UAS), as described in chapter 6.2.8; and space-based sensors, as described in chapter 6.2.9.

6.2.7 *Man-machine integration*

There is limited information available about military man-machine integration developments in Russia. However, the increasing focus on AI-based technologies, automation and autonomous systems could mean that Russia could gain an edge in human-machine teaming. The predominant advantage to be gained is the speeding up of the decision cycle, which requires intelligent decision support systems (IDSS). These systems have specialised functions that perform tasks related to decision-making, including data mining and machine-learning, knowledge representation, intent recognition and automated interference.

Russia is one of the three nations (besides China and the US) that is almost done with the development of such human-AI teams, which has serious future potential. Military efficiency can be improved when the systems are designed in a way that AI supports strategic decision-making, but that the humans are not solely dependent on it. A human member of the team should be able to take over when AI fails, just like that the AI should be able to identify when human decision-making could be compromised (Blumenthal, Hottes, Foran, & Lee, 2021).

6.2.8 *Weapons*

Russia has emphasised the development of high-end technological weapon systems, ranging from new missile systems, to innovative military applications for legacy ground vehicles, and novel unmanned ground, naval, and aerial systems. Whilst the Russian Federation is working on a wide range of innovative weapon systems, we have limited this chapter to the most impactful weapon system categories: Missile weapon systems, tanks, artillery, UAS, UGVs, UUS, DEWs and space weapons. Especially the so-called 'super-weapons' that Putin referred to in its March 2018 speech to the Federal Assembly, have caused great concern amongst Western governments, and weapons experts.

<u>Missile weapon systems</u>
Some of Russia's most advanced missile systems include:

- Avangard and Tsirkon: Both hypersonic missiles. The first two Avangard systems have already entered service in 2019. The Russian Federation aims to rollout at the very least two fully equipped missile regiments by the end of the GPV 2027 programme (Bendett, et al., 2021). The Tsirkon is a scramjet powered maneuvering anti-ship hypersonic cruise missile currently in production by Russia.
- RS-28 Sarmat: The RS-28 Sarmat, liquid-fuelled, silo-based, intercontinental ballistic missile (CIBM) has entered service in late 2021. The RS-28 Sarmat is expected to be able to carry a range of different payloads, including conventional and nuclear warheads, and could also be equipped with the Avangard hypersonic glide vehicle as a gliding platform for the RS-28 missile (Bendett, et al., 2021).
- 9M730 Burevestnik 'Skyfall': This cruise missile would be the first of its kind as a nuclear-powered cruise missile, which would remove the typical range limits of cruise missiles. The capability to fly at lower altitudes, at extended ranges and longer durations through its nuclear propulsion system would be true gamechanger in the global field of cruise missile development. However, engineering challenges remain with the development of a miniaturised nuclear-capable propulsion systems for the weapon system (Sanger & Kramer, U.S. Officials Suspect New Nuclear Missile in Explosion That Killed 7 Russians, 2019).
- Poseidon : In addition to these ground-launched systems, Russia has been developing the 'Poseidon', a nuclear-powered underwater torpedo that can be equipped with both conventional as well as nuclear warheads. This system will be launched from nuclear-powered submarines. The Poseidon system might be a stepping stone towards a testbed on Unmanned Underwater Vehicles (UUVs), intended to eliminate constraining factors for manned underwater systems, which would enable these UUVs to have a competitive edge over its manned nuclear-powered counterparts in terms of range, speed, and endurance capacities (Bendett, et al., 2021).

<u>Tanks</u>
The Russian Federation benefits from a large arsenal of Soviet legacy armoured vehicles. Instead of pursuing a large-scale endeavour to replace current tank equipment with new, technologically innovative, high-end material, the Russians have opted to upgrade these older systems with improved sensors, defence systems, and weaponry (Radin, et al., 2019). This retain-and-adapt strategy aims to maintain Russia's global dominance vis-à-vis mechanised capabilities without a complete replacement of its large mechanised arsenal at minimal costs. Previous efforts to develop a new main battle tank, like the T-14, were unable to reach their intended acquisition track. Initial plans to purchase 2.300 T-14 tanks by 2020 was scaled down to merely 100 tanks by 2022 (Global Security, sd). Soviet legacy systems like the T-90 and the T-72 Main Battle Tanks will be outfitted with the

improved Active Protection System ARENA-M which is intended to protect these tanks from FGM-148 JAVELIN man-portable anti-tank missiles and SPIKE Anti-Tank Guided Missiles (Laskin, 2021). In addition, the Russian armed forces seem to be experimenting with slatted armour on its tanks, to improve protection against sUAS (Roblin, Russian Tanks Massing Near Ukraine Sport Mods Against Drones, Javelin Missiles, 2021).

Artillery
The Russian artillery modernisation programme is similar to that of its manoeuvre ground forces as described above. The Russian indirect fires capability ranking number 1 globally is a legacy from the huge arsenal of launcher and munitions equipment from its Soviet Union predecessor (Radin, et al., 2019). Modernisation efforts focus on minor revisions to its systems, rather than major upgrades or the development of entirely new systems. The Tornado-G and Tornado-S systems are direct successors of and are very similar to their legacy counterparts of the BM-21 Grad and BM-30 Smerch respectively (Military Today, sd) (Military Today, sd) (Military Today, sd) (Military Today, sd) (Radin, et al., 2019). The Russian operational approach towards indirect fires focuses on effectiveness through mass, rather than precision fires which the West has been pursuing. Artillery accuracy and precision are instead enhanced by improved ISR capabilities provided by UAS, in what is known as artillery spotting (Michel, 2020).

Directed Energy Weapons
The Russian Federation has conducted research into Directed Energy Weapons (DEW) since the 1960, in particular in relation to High-Energy Lasers (HEL) (Sayler, Emerging Military Technologies: Background and Issues for Congress, 2021). The Russian Airforce has reportedly equipped its Su-57 and MiG-35 fighters with laser weaponry designed to disable incomingg hostile missiles by dazzling its sensory equipment (Pravda, 2017) (Military Watch Magazine, 2020). The Peresvet laser system was publicly unveiled in 2018. Whilst the specifics are not publicly known, it is likely that this is a mobile air and/or missile defence laser system, given the deployment of these systems near road-mobile ICBM bases (Bendett, et al., 2021). It has also been suggested that the Peresvet system might be capable of dazzling satellites' optical sensors (Hendrickx, Peresvet: a Russian mobile laser system to dazzle enemy satellites, 2020). Other possible developments in Russian DEW research and development is unfortunately shrouded in secrecy.

6.2.9 Space

Russia has long worked on the possible weaponisation of space. The Russian Federation established its space forces as a separate branch within the Air and Space Forces (VKS). Its areas of responsibility include: early warning of ICBMs, situational awareness in space, satellite launches and operations, and the maintenance and readiness of space infrastructure. The space forces are explicitly responsible for threats in and from space. Implicitly this signals that Russia does not perceive space to be a domain for offensive capabilities, although they are not explicitly ruled out.

The 1967 Outer Space Treaty (OTS) bans "the stationing of weapons of mass destruction (WMD) in outer space, prohibits military activities on celestial bodies, and details legally binding rules governing the peaceful exploration and use of space" (Kimball, 2020). The FOBS capability tries to circumvent the treaty by arguing that legally a FOBS capability is not in violation of the OTS, since the weapon system in question would not make a full orbit around the earth before arriving at its target. A flimsy legal argument at best, given that orbit is a condition rather than an altitude or fulfilling a full orbital loop. The Avangard hypersonic glide vehicle is a platform that could be used for such a FOBS capability in the future, should the Russians decide to pursue this capability like the Chinese are doing. As of yet, we have not seen signals to that effect. Even though no programmes are in development to weaponise space by the Russians, American, Chinese or any other country, it seems that anti-space weaponry is being pursued by the Russian Federation.

Anti-Satellite weapons

The Russians seem to focus their space efforts on Anti-Satellite weapons (ASAT). In November 2021, the Russian Federation conducted an ASAT weapons test and successfully destroyed an obsolete Electronic Signals Intelligence (ELINT) satellite with the A-235 Pl-19 Nudol anti-ballistic missile system, which drew widespread condemnation due to the dangers of resulting space debris (Atwood, Sciutto, Fisher, & Gaouette, 2021). This is a worrying development, the use of ASATs in a war could quickly escalate both sides to take out its adversaries' satellites, both military and civilian, which would result in catastrophic fallout in societies that have become so dependent on services enabled by satellites, including telephone and internet connections. Even more worrying, escalating to ASAT weaponry would disable early warning satellites which would obscure countries' early warning capabilities on incoming missiles, further escalating countries towards mutually assured destruction in response (Blatt, 2020).

GLONASS

The Russian Federation has developed its own Global Navigation Satellite System (GNSS), named GLONASS, the Russian counterpart to the US Global Positioning System (GPS). GLONASS consists of a 24-part satellite constellation that provides an accuracy similar to GPS. As with GPS, GLONASS was initially only used for military purposes, but since 2007 it has been approved and adopted for civilian use. Whilst the sanctions on Russia will impede the speed of Russian modernisation of its GNSS, they will likely continue its modernisation programme given the central role of GNSS in military operations and civilian daily life.

Liana programme

Russia started an Electronic Intelligence (ELINT) satellite modernisation programme soon after the dissolution of the Soviet Union. The programme Liana launched in 1993 was intended to replace the satellite for ELINT in use by the Foreign Intelligence branch of the Russian MoD (GRU), named the Tselina, and the ELINT satellite in use by the Russian Navy named Legenda. The Liana project aims to build modern replacement satellites for both the Navy and the GRU, which would have passive ELINT systems and an active radar system. The Pion satellites, intended for the Russian Navy, would additionally have an active radar system. Yet the project has experienced severe delays. Its initial test flights were planned in 2004, yet the Pion satellite intended for Navy use is still on ground and undergoing further research and testing (Hendrickx, The status of Russia's signals intelligence satellites, 2021). In the meantime it is likely that the GRU's Lotos satellites, the first of which was launched in 2009 with replacement satellites being launched once the lifespan of the previous Lotos satellite was reached, are servicing both the GRU and the Navy. The specific capabilities of the Liana programme remain a well-guarded secret. A Russian Navy journal does specify capabilities for modern space-based ocean reconnaissance systems, which include providing target acquisition data for anti-ship missiles, monitoring of enemy naval formations, the surveillance of maritime bases, observing hydrometeorological conditions for naval operations, and early warning of sea-launched attacks (Bychkov & Cherkashin, 2021). It is not clear whether this is implicitly referring to the intended or actual capabilities of the Navy Pion satellites, or perhaps a future programme.

<u>Remote sensing</u>
Russia is still catching up when it comes to a space-based remote sensing capability. Sophisticated photoreconnaissance and GEOINT are highly useful capabilities for the identification and tracking of adversarial systems and terrain, as showcased by the revelations of Chinese missile installations over the last year (Warrick, 2021). After the failed launch of the Persona satellite in 2008, and dissatisfying performances of successfully launched Persona satellites in 2013 and 2015, the Russian Federation has opted for a new programme known as Razdan. This programme will provide a photoreconnaissance capability. This programme too has experienced severe delays. Plans envisioned the deployment of three satellites between 2019 and 2024, but as of the November 2021 no satellites have been launched (Bendett, et al., 2021). The Obzor-R, which would be Russia’s first Synthetic Aperture Radar (SAR) satellite, will provide the Russian Federation an all-weather high resolution land observation and monitoring capability (Observing Systems Capability Analysis and Review Tool, sd).

6.2.10 3D printing and new materials
The company Rusatom Additive Technology (RusAT) – which is a daughter company of TVEL Company and the Russian state-owned nuclear firm Rosatom – opened its first Additive Technologies Center at the beginning of this year. The facility is able to combine development, engineering and manufacturing. It has installed 3D printers that can produce metal powders, post-processing equipment and a product research lab to then develop the additive manufacturing technologies. The Center is located at the Moscow Polymetal Plant and features a fully 3D-printed anti-debris filter for a nuclear fuel assembly. The aim is to launch a full production cycle for additive manufacturing products as soon as possible (Metal AM, 2021).

It is unclear how this centre would be used for military purposes. However, since the Russian defence industry has already used 3D printing to produce prototype components for the T-14 main battle tank and the rest of the Armata family of combat vehicles, it can be expected that this trend continues and eventually even the standard components will be 3D printed (Majumdar, 2016).

6.2.11 Biotechnology
In 2012, Russia released a whole-of-government strategy to boost its biotechnology sector. The priority areas for relevant research include biopharmaceutics and biomedicine, industrial biotechnology and bioenergetics, agricultural and food biotechnology, forest biotechnology, environmental protection biotechnology, and marine biotechnology (BIO2020). However, it is unclear in what capacities Russia might use development in this sector for dual-use purposes, because limited public

information is available. It can be argued that the country does not shy away from using biological agents as a weapon, as it was accused of using a Novichok nerve agent to poison a former Russian double agent in the United Kingdom in 2018 as well as the main Russian opposition leader Alexei Navalny in 2020 (BBC News, 2020). This was also confirmed by the US End-User Review Committee (ERC) as it argued to have a reasonable cause to believe that three Russian research institutes are associated with a long-standing Russian biological weapons programme; Biopreparat (Sayler, Emerging Military Technologies: Background and Issues for Congress, 2021).

6.2.12 Simulation and virtualisation

In March 2021, RPA RusBITech, a Russian technology company, demonstrated a new digital simulation system that integrates simulators of weapons and other military equipment into a virtual battlefield. The Spektr-7E uses the live-virtual-constructive (PVC) concept, and can thus be used for various levels of training for all the military branches and units (Armada International, 2021).

6.2.13 Human Performance and Training

Russia is developing technologies targeting Human Performance Enhancement (HPE). This includes research on improving brain-computer interface (BCI) and the development of human-AI teams, as discussed in the sub-chapter on man-machine integration.

6.2.14 Robotics and Autonomous systems

Russian defence policymakers and the defence industry deem robotics and autonomous systems as a potential gamechanger for the future of war. Such perceptions are reflected in Putin’s statement in at a session of the military and industrial commission in 2017: “Autonomous robotized systems are… capable of principally changing the entire system of armaments of general-purpose forces” (TASS Russian News Agency, 2017). Likewise, the head of the Advanced Research Foundation stated in 2017 that “combat will be a war of operators and vehicles – the soldier will gradually turn into an operator and move away from the battlefield.” (RIA Novosti, 2020). The Russian Military Industrial Committee has approved a plan that would have 30% of Russian combat power consist of entirely remotely controlled and autonomous robotic platforms by 2025 (Thomas T. , 2021).

<u>UAS</u>

Russia lagged behind in its UAS R&D after the fall of the Soviet Union. Compared to UAS leading countries like the United States, Israel, China, and Turkey, Russia was very late in rolling out a UAS development and acquisition project which started in 2011. The focus of the UAS Class 1 project was on small UAS, with a focus on short range ISR and mission support capabilities. The best known, and most used systems resulting from this initiative are the Orlan-10 and Granat-2 class I UAS, which are both short range, tactical ISR UAS and have been used extensively in Syria and the Donbass (Lucassen, Lassche, Malone, Clisby, & Cadet, 2021). In addition to such ISR UAS, the Russian Federation has also developed and used loitering munitions systems like the ZALA LANCET-1, which are launched with a pneumatic launched system that can reach targets at a range of +/- 40 km with an explosive strike capability. Recognising the gap between Russian expertise on UAS compared to leading UAS countries, especially with regard to class II and III UAS, the Russian Federation has contracted Israeli UAS industry to deliver adapted IAI

Searcher II UAS (class II), licensed under the name Forpost-R. Simultaneously, Russia has been further developing its domestic class II and III UAS R&D and production. The class III Orion UAS entered service in 2020, and an even larger adaption of the original Orion UAS known as the Inokhodets-RU (also known as Sirius), is being developed with a first flight test envisioned in 2022 and service-entry in 2023 (TASS Russian News Agency, 2021). These systems are expected to fulfil missions similarly to how the US use the MQ-1 predator UAS (Newdick & Rogoway, Russia's Predator-Style Drone With Big Export Potential Has Launched Its First Missiles, 2020).

<u>HALE UAS & manned aircraft teaming</u>
The US have moved on from the MQ-1 Reaper, and predominantly use the MQ-9 Reaper, which is a significantly more sophisticated unmanned High-Altitude, Long-Endurance (HALE) class III UAS. Similarly, the Russian Federation is developing the Sukhoi S-70 Okhotnik (Hunter) UAS, which is expected to start tests in 2023, and a launch of production in 2025 (Newdick, Now Russia Wants Its First Okhotnik Combat Drone In Service By 2024, 2020). The S-70 is expected to fulfil a ‘wingman’ function in coordination with the Su-57, manned aircraft, where the S-70 provides target acquisition and enhances the sensing capabilities of the Su-57.

<u>UGVs</u>
Whereas the Russian experimentation with UAS has been an overall success in its deployments in the Donbass and Syria, the same cannot be said of its Unmanned Ground Vehicles (UGVs). In 2012 the Russian Federation established the Russian Ministry of Defence’s Main Research and Testing Centre of Robotics, which would facilitate the research and development on UGVs. The Russian have since 2013 envisioned a variety of possible tasks for UGVs, including: breaking through fortified enemy positions; forming strongpoint defensive positions; fire support for fire offensives; target acquisition and fire control for artillery; bomb disposal; mine laying and mine clearance; and delivery of munitions and fuel to units under fire. The Russian military has developed and tested many types of UGVs with various of these duties, ranging from smaller UGVs like the Uran-6 with mine clearing capabilities, to larger, armoured combat vehicles with heavy weaponry like the Uran-9 (European Security & Defence, 2019). Operational testing in Syria however showed severe problems with the use of such UGVs in practice. Whilst the demining capability of the Uran-6 was highly rated by Russian engineering forces, the usefulness was limited by the operators’ remote position from the vehicle in combat conditions. Likewise the Uran-9, which was developed as an unmanned alternative to Russian battle tanks, which the Russian Federation has historically heavily relied on, experienced multiple points of failure in combat conditions ranging from communication, transportation, firing, and operators’ situational awareness issues (Bendett, Blank, Cheravitch, Petersen, & Turunen, 2020).

The Russian military for the moment expects UGVs to only be useful in specific and limited scenario’s, for example for demining tasks in non-combat conditions. For the longer term, issues surrounding communications and especially remote operators’ situational awareness will need to be resolved before mass deployment of UGVs can be useful. The Syrian operational experience has shown the Russians that for the time being, a conventional attack with a reinforced mechanised company is more effective than UGVs (European Security & Defence, 2019). It is likely that developments in AI, improved UGV design and combining the ISR capabilities of

UAS in conjunction with UGV operations could resolve the issues that are currently impeding the effectiveness of UGVs in the Russian armed forces.

<u>UUVs</u>
The Russian Federation is researching possible uses for Unmanned Underwater Vehicles (UUVs). The Russian navy has been testing various systems like the Alexandrite-ISPUM demining UUV and the Vityaz-D deep-sea UUV, which is equipped with various electro-optic, sonar, and echo sensors as well as AI-enhanced navigation that is supposed to avoid obstacles and identify confined spaces. The use of UUvs could expand Russian capabilities in search and rescue efforts, demining missions, bathymetric surveillance, bottom topography, and measuring hydrophysical parameters of the marine environment (Naval Technology, 2020).

<u>Swarming</u>
In 2017, Russia expressed a clear ambition with regard to drone swarming, namely to create a swarm of autonomous robotic systems capable of independent decision-making, conducting combat operations, and reconnaissance within 5 years (by end of 2022) (TASS Russian News Agency, 2017). This ambition has not yet been realised, and Russian researchers have admitted that many issues in developing useful algorithms that can account for the unpredictability and uncertainties of combat conditions especially when facing adversaries with high-end military capabilities, secure communications between drones, and the communications and C2 links between the swarms and human operators need to still be resolved to acquire an operational swarming capability (Grinkevich, 2021). For UGV swarming capabilities the Russian operational experiences have shown that communications within the swarm and between the swarm and human operators is further impeded by obstructions like buildings and terrain in the operational area. UAS have a clear advantage over UGVs in this regard. The Russian approach towards swarming seems to focus on a ‘hybrid’ swarming infrastructure, where swarms have a designated ‘leader’ platform within the swarm that is in charge of communications and C2 within the swarm (Flying Ad-Hoc Network swarming architecture (FANET)), and another link between the robotic leader and the human operators in the Ground Control Station (infrastructure-based swarming architecture) (Asaamoning, Mendes, Rosário, & Cerqueira, 2021). Such a hybrid swarming capability is also being developed for the Flock-93 UAS (Zakvasin, 2019).

The Russian Federation will not be able to realise its ambition to have a robotic swarming capability operational for either UAS or UGVs by the end of 2022. It is likely that efforts will refocus on developing a hybrid swarming architecture for UAS over the next decade.

6.2.15 ICT and networks

Since a decade Russia is increasingly using high-technology to transform military decision-making. On the one hand it has been trying to simplify and digitalise its C2 system (the YeSU TZ) as well as procure automated ones. On the other hand, Russia aims for network-centric approaches and whereby the automated C2 should fit the adaptation of C4ISR. On a tactical level this includes new tactical radios, a tactical digital mobile subscriber system (military digital cell phone and data system), tactical laptops and tablets, as well as a secure military intranet. The adoption and introduction of automated C2 increased the speed and efficiency of Russian military decision-making in conflict. However, two problems involved with such a complex system in the information space are present: interoperability and information conflict (McDermott R. , The Revolution in Russian Military Decision-Making, 2021). While official Russian policy documents do address the problems of interoperability and standardisation, but do not offer concrete ways ahead. One problem is that the different Russian military services use different automated systems (McDermott R. , Tracing Russia's Path to Network-Centric Military Capability, 2020). In short, while Russia is innovating on the technological level, as long as the level of work on ICT standardisation remains low and interoperability issues are not solved, the efficiency and effectiveness of its automated C2 system and the transition to C4ISR will be limited.

In the future it is expected that Russia continues to invest in modernising C4ISR capabilities. Based on the public available information, around 40% of the Ground Forces could be network-enabled by 2030, and that percentage will rise to 100% in the elite forces (McDermott R. , Tracing Russia's Path to Network-Centric Military Capability, 2020).

6.2.16 Behavioural engineering

Russian behavioural engineering capabilities have been extensively applied over the last decade. The Russian Federation attempted to influence democratic elections in the Netherlands, France, Germany, the United Kingdom, Sweden, and of course the United States (Brattberg & Maurer, 2018). Rather than trying to sway elections in the favour of a preferred candidate, Russia would target both sides to sow division and decrease faith in democratic institutions and processes (Kim Y. , 2020). The use of ‘troll farms by Russia to disseminate and reinforce disinformation, misinformation, and propaganda is one of the most well-documented behavioural engineering practices in the cyber domain (Sultan, 2019) (Helmus, et al., 2018) (Francois, 2021). In addition to using human trolls, the Russian Federation has used automated bots, and even fake publication outlets, and deep-fake profiles to convince the reader of the authenticity of the content (Wong, 2020). Applied AI in the form of Generative Adversarial Networks (GAN) are constantly training to improve algorithms to generate more realistic synthetic images of human faces (Venkataramakrishnan, 2020). As such AI applications improve, the quality and quantity of behavioural engineering capabilities will expand.

The Russian Federation has also used behavioural engineering capabilities in the Baltics, with the aim of degrading the effectiveness of NATO eFP forces (Fabian & Berzins, 2021). Given the effectiveness of Russian behavioural engineering in both election interference, and in operational context, and the development of an AI roadmap signals a Russian intent to continue using and improving behavioural engineering capabilities into the future.

6.2.17 Energy

Russia is the world’s fourth biggest producer of energy worldwide, and the 14th biggest exporter of energy, with crude oil, petroleum products and natural gas being the greatest sources of revenue from Russian exports (Central Intelligence Agency, 2022) (Trading Economics, 2022). As such, it is paramount for the long term stability of the Russian state to have a clear future energy strategy. In June 2020, the Russian Federation released its new Energy Strategy to 2035 (The Government of The Russian Federation, 2020).

Following the publication of the Energy Strategy to 2035, the Russian Federation released in October 2020 its Roadmap for Hydrogen Development until 2024, which describes a plan to develop a domestic hydrogen energy sector in Russia (The Government of the Russian Federation, 2020). Russia is well situated to become a hydrogen energy production on global markets. Skills and expertise from the oil and gas sector are easily transferable to the hydrogen energy sector; in addition Russia already has some relevant expertise on the production, transportation and storage of hydrogen fuel (Barlow & Tsafos, 2021).

Information regarding the use of energy in the defence context could not be found.

6.3 Official sources

The table below shows the sources that have been consulted.

Title	Comments	References
Russian Federal government website.	Announcements and publications on official public policy.	http://government.ru/
Morskoy Sbornik.	Russian military naval journal for officers. Intended to explain policy, theory, and practice on Russian military naval issues.	https://morskoysbornik.ric.mil.ru/
Russian News Agency [Информацио́нное аге́нтство Росси́и] TASS	Largest Russian news agency, owned by the government of Russia. Often used for dissemination of and commentary on public policy.	https://tass.ru/

7 South Korea

7.1 Overview benchmark results

7.1.1 General data and assessment results

The table below presents key data that reflect South Korea's[30] geopolitical challenges and drivers as well as its strengths and general facts relevant to the defence and security environment.

SOUTH KOREA: GENERAL INFORMATION	
Geopolitical challenges and drivers	• Threat from North Korea • Territorial disputes with China and Japan
Strengths	• Strong military alliance with the United States • A global economic and industrial powerhouse
Defence budget [2020]	• $45,7 bn (2,8% of GDP) (Stockholm International Peace Research Institute, n.d.) • $892 per capita • 10,9% of total government budget
Defence size [2020]	• 555.000 active personnel (Ministry of National Defence, Republic of Korea, 2021)
Defence R&T budget [2021]	• $3,9 bn (Army Technology, 2021)
Defence R&T partner countries	• Cooperation agreements with 39 countries[31] • Most prominent partners: United States, France, United Kingdom, Israel, India, Singapore and Australia
Arms industries	• Hanwha Aerospace, Korea Aerospace Industries, LIG NEX1, Hyundai Rotem, Daewoo Shipbuilding & Marine Engineering
Arms export [to]	• United Kingdom, Indonesia, Philippines, Thailand, India, Iraq (Stockholm International Peace Research Institute, n.d.)
Arms import [from]	• United States, Germany (Stockholm International Peace Research Institute, n.d.)

The following table provides a summary of the key findings for each of the 15 SKIA technology areas. The column 'Focus' indicates the level of priority the referent country gives the respective technology area vis-à-vis other technology areas: high (+), moderate (0) or low (-). This reflects the governmental attention, based on policies, plans and investments, as well as concrete activities in research, technology and innovation. Also, it demonstrates the level of technological development that one can expect from a powerful military player.

[30] Officially South Korea is referred to as the Republic of Korea (ROK); in this report we use the name South Korea to avoid confusion with North Korea.
[31] Defence White Paper 2020 states: 39 countries that have signed defence industry cooperation agreements (MOUs), 18 of which have technical cooperation at the core of the MOU with the ROK (Ministry of National Defence, Republic of Korea, 2021).

SOUTH KOREA: TECHNOLOGY AREAS			
Technology Areas		**Focus (+,0,-)**	**Findings**
1	Artificial Intelligence	0/+	• Strong ambition to apply AI for unmanned systems and cyber technologies • Civil sector (industry and research institutes) team up with Ministry of National Defence[32]
2	Cyber & Electromagnetic Activities	0	• Reinforcing the functions and performance of the cyber-operation system • Growing attention for EMA but not yet top- notch
3	Quantum	0	• One of 15 nations with a substantial national quantum research programme • No information about MND investments and activities on quantum, but it is likely that there will be a spin in • Investing in Atomic Technology, which enables long-term quantum navigations under GPS-free environments.
4	Sensor	+	• Large variety of sensor developments (ground, air, naval) for all kinds of threats • North Korean artillery and missile threat enforces development of improved sensors • Photonic radar technology to detect multiple small and stealthy threats with precision
5	Man Machine Integration	0	• South Korean institutes have a strong position in human-system interaction • It is expected that there is an influx of advanced concepts into the military, however not much proof is found
6	Weapons	+	• Due to North Korean threat a large focus on defensive weapons, and growing attention for strike capabilities • Research on hypersonic weapon technology, aiming to have hypersonic weapons in 2026
7	Space	+	• Huge investments on the short and long term • National development of its own satellite navigation system
8	3D printing & Materials	+	• 3D printing is becoming central to South Korea’s defence industry • Academia claim interesting metamaterial successes with potential military applications.
9	Biotechnology	0	• South Korea is one of the front runners in biotechnology in the civil sector • Applications in the military are unknown; only some limited research on synthetic biology
10	Simulation & virtualisation	+	• To realise a smaller military work force, advantages of simulation technology will be fully exploited • Adoption of Live, Virtual. Constructive, Gaming is already on the brink
11	Human Performance & Training	0/+	• Increased attention and investments in physical, cognitive and mental abilities • Utilisation of big data for improving safety and health of the military
12	Robotics & Autonomous systems	+	• Rapid introduction of all kinds of unmanned and autonomous systems due to demographics and threat drivers • Army Tiger 4.0 system fielded in 2024 to employ AI-powered drones to facilitate decision-making on the battlefield

[32] The South Korean Ministry of Defence is formally referred to as the Ministry of National Defence (MND). Therefore we will use this term and its abbreviation MND throughout this chapter.

SOUTH KOREA: TECHNOLOGY AREAS		
Technology Areas	**Focus (+,0,-)**	**Findings**
13 ICT & networks	-/0	• Ambitious plans, but first steps towards an advanced ICT/network environment has to be made; initial research on Terahertz technology • Existing operational concepts are single domain/services, and miles behind new concepts like Multi Domain Operations
14 Behavioural engineering	0	• Although important expertise in conflict with North Korea, military use restricted due to undesired past use towards own population • Academic field performs on a moderate level
15 Energy	-/0	• South Korea is a laggard in applying energy from renewable sources • Some niche research topics: water batteries, self-generated electrostatic energy, Perovskite solar cells.

7.1.2 Takeaway's

The key takeaway's for the assessment of South Korea's ambitions and activities on military science and technology are:

- Due to demographical reasons the military force has to transform in a smaller but more intelligent-based force for which AI, autonomous systems and simulation technologies are key enablers. Therefore South Korea has selected these technologies, amongst others, as high priority areas.
- Due to the proxy threat of a North Korean rocket and missile attack, South Korea invests substantially in capabilities that improve the sensor-to-shooter chain, e.g. early warning sensors, counter battery sensors, a 24-hours satellite-based surveillance system, ICT-networks for speeding up information processing and a wide range of interceptors.
- Interesting 'niches' in which South Korea invests include utilisation of big data for improving safety and health of the military, improving mental and spiritual abilities of soldiers and 3D printing of existing and future products.
- Energy technology seems to be the lowest priority area (of all 15 assessed technologies) for the South Korean military. On the civil side (both government and industry) the green deal is not yet very high on the agenda, if compared to similar economies, which is probably the main cause that also the military is lagging behind on this topic.

7.2 Benchmark analysis

This subchapter presents the actual benchmark analysis upon which the table above and the key takeaway's are based. It starts with an introduction, after which it zooms in on South Korea's research, technology and development base in general. Following, it analyses each technology area more in-depth. It ends with a concise table with the most important official sources used.

7.2.1 Introduction

South Korea is surrounded by possible threats. Probably the most severe threat is the threat from its northern neighbour North Korea, in particular its nuclear weapons. Since North Korea's army has about 1.1 mln ground troops and the bulk of them are located near the Thirty-Eighth Parallel, the South Korean military has historically focused on ground forces. But as North Korea is now armed with nuclear warheads and wide-ranging ballistic missiles, including sea-launched ballistic missiles, South Korea's armed forces must be reconfigured to meet a growing array of asymmetrical threats. Meanwhile, China's A2/AD capabilities – including sophisticated anti-ship missiles and growing air and naval power – could significantly constrain, deter, or even deny the possibility of coordinated US-South Korean and/or US-Japan military operations in acute crises or wars. Another potential threat could ironically be caused by the collapse of North Korea, since this could trigger China to intervene militarily on the Korean Peninsula.

But also China's assertive rise and ambitious dreams of dominating the seas in the Indo-Pacific is a threat to South Korea. In that region there are several disputed islands and areas, foremost in the South Chinese Sea, which leads to tensions, verbal threats and violations of airspace and the law of sea between some of the regional great powers An additional challenge is the relationship with Japan, which has been deteriorating in the last years. Testifying to the soured ties, the white paper referred to Japan as a "neighbouring country" similar to China, an ostensible demotion from its reference to Japan as a “strategic partner" in its 2018 white paper (Kyu-Seok, 2021).

The national security strategy defines South Korea's goal for security as follows: “*to establish a peaceful and prosperous Korean Peninsula through a peaceful resolution of the North Korean nuclear issue and the establishment of permanent peace; contribution to peace and prosperity in Northeast Asia and the world; and the realisation of a society where people's safety and lives are protected.*” (Ministry of National Defence, Republic of Korea, 2021).

The national defence policy and military strategy is derived from the national security strategy and defines three main goals:

- protecting the nation from external military threats and invasion;
- supporting a peaceful unification of the Korean Peninsula;
- contributing to regional stability and world peace.

In 2018, South Korea's Ministry of National Defence has started with reforming its defence forces into a steadfast national defence to realise this strategy. A substantial increase of the annual defence budget was approved by parliament. Based on the latest mid-term defence plan for 2022-2026, 271.5 bn USD have been allocated towards defence, starting with 47,6 bn USD in 2022. This represents a 5,8% increase over the proposed allocation in the previous plan (2021-2025). One-third of the defence budget is meant for force modernisation including procurement and R&D (Grevatt & MacDonald, 2021).

South Korea has the world's tenth-largest budget and its armed forces are ranked as the sixth most powerful military as of 2021 (Global Firepower, 2021). Nevertheless, South Korea is also facing internal challenges affecting the military. Its rapidly changing demographics will enforce South Korea's armed forces to shrink. To offset the military's dwindling supply of soldiers, the country is reforming its forces to accommodate a necessary reduction from a 599,000-strong force to a size of 522,000 troops by 2022, of which 274,000 are conscripts. The latter is expected to shrink even faster (almost 50% less supply of conscripts by 2039) (Lee C. , 2021).

The MND asserts it can cope with significant manpower shortages by transforming the military into a high-tech force and recruiting and/or engaging more civilian specialists. The severe reductions will mainly hit the army.

7.2.2 Research, Technology and Development in general

South Korea is a global economic and industrial powerhouse and is identified as a world leader in shipbuilding, motor manufacturing and information technology. It also has progressively become a global innovation leader, being at the frontend of applying cutting-edge technologies like IoT, big data, quantum computing, advanced materials and nanotechnology (including material used in the renewable energy sector and wearable technology), and health related technologies (OECD, 2015). The Bloomberg 2000 Innovation Index, which measures R&D spending, patent activity, productivity and manufacturing output, has been ranking South Korea in its top tier for the past 6 years (Jamrisko & Lu, 2020).

South Korea’s innovation power and success is based on several conditions (Dayton, 2020):

- Its society and citizens are very open to innovation and technology and they have a very particular cultural characteristic of pushing things to happen quickly and effectively.
- Government intervention and investment in supporting R&D and technological innovation have brought rapid and long-lasting results. In the past six decades, the state pushed for a policy-ushered shift from dependency on technology imports and foreign companies to a home-grown base of large industrial groups. It meanwhile spends more on R&D than any other economy.
- The government started at the beginning of the 21st century to develop regional innovation centres and cross-sectoral movement of researchers between industry and academia. This has bridged the business and research divide.

Also in the defence sector South Korea has become one of the most advanced producers of military equipment in the world. The strengthened role of the industry in the defence R&D sector, in particular in shipbuilding, machinery and electronics, has been the key for this success. This does not imply that it is fully self-sufficient. There are still certain areas of defence production where it remains highly reliant on foreign-supplied core technologies, including but not limited to aircraft engines, thermal imaging sensors and flight control systems. Thus, many of the high-tech weapon systems produced in South Korea have been developed through the technological assistance of foreign contractors, predominantly originating from the US (Korkmaz & Rydqvist, 2012).

The Defence Acquisition Program Administration (DAPA) is responsible for the acquisition of national defence capabilities (Defense Acquisition Program Administration, sd). It was founded in 2006, and it has an extensive interaction with the Agency for Defence Development (ADD), which provides knowhow and technology to DAPA to ensure the development and acquisition of the best systems for the MND. The ADD is one of the cornerstones of South Koreas military innovations. Founded in 1970, its mission is to contribute to the reinforcement of national defence power and the accomplishment in self-reliance of national defence by taking charge of the technical survey, research, development, and testing of weapons, equipment, and supplies required for national defense as well as the survey, research, and testing of science and technology related thereto (ADD - Agency for Defense Development, sd).

For 2021 the government had planned to spend 3.9 bn USD on defence related R&D, which is about 9% of the total defence budget. The R&D spending is an increase of 10% compared to 2020. This significant increase is meant to strengthen Korean's defences capabilities to secure advanced technologies (Army Technology, 2021).

In 2021 the MND formally launched its new agency to support the development of the country's defence technology and industry base, the Korea Research Institute for Defence Technology Planning and Advancement (KRIT). The aim of KRIT is to modernise the country's system for defence technology planning and management, strengthen the domestic defence industry, increase the international competitiveness of South Korean military technologies, and support industrial expansion in overseas markets. For the defence technology planning the KRIT investigates and monitors foreign defence science and technology, weapon system/technology development status and development trends thereof, and newly required technologies in the future. This is the basis for developing domestic R&D policies and strategies (Korea Research Institute for Defense Technology Planning and Advancement (KRIT), sd).

The MND's '2022-2026 Mid-term Defence Plan', released in August 2021, announces that intensive investments will be made in the acquisition of new 4th-Industrial-Revolution-era technologies for defence and in basic research and the development of the designated eight core defence strategic technologies (Ministry of National Defence, Republic of Korea, 2021). These key strategic technologies include:

- Autonomous and AI-based surveillance and reconnaissance;
- Super-connected intelligent C2;
- Super-high-speed and high-power precision strike;
- Future oriented propulsion and stealth-based platforms;
- Manned and unmanned mixed force warfighting;
- Cutting-edge technology-based individual combat system;
- Active cyber response and future protection;
- Future cutting-edge new technology; within the ADD the following future technologies have been prioritised (ADD - Agency for Defense Development, sd): ÀI, Blockchain, Military IoT, Quantum, Photonic Radar, Atomic, Terahertz, Perovskite Solar Cell, New energy, Synthetic biology, Metamaterial for stealth, Biomimetic Robot, Swarming, Boost Phase Intercept, Counter Long-Range Artillery Interceptor Jamming and K-Mosaic Warfare. Further elaboration of these technologies is covered in the next sections since these all relate to one or more SKIA technology areas.

To utilise civilian R&D capabilities needed for future battlefield innovation in defence, the MND plans to contribute to national (civil driven) R&D activities in various ways and extend the scope of application by developing defence technologies and weapons systems for 10 fields: advanced sensors, AI, mixed reality, quantum information, cybersecurity, IoT/Everything, energy, new materials, 3D/4D printing, and unmanned robots (Ministry of National Defence, Republic of Korea, 2021).

As an example, in September 2021 a new partnership between South Korea's MND and Ministry of Science and Information and Communications Technology has been started. Its goal is to advance digital technology to meet the nation's evolving defence needs. Unmanned systems, such as drones and robots, cyber defence and modernisation of scientific and alert systems are among these needs and priorities. The partnership also includes specialised education for military officers and non-commissioned officers to acquire skills in software and AI (Kim F. , South Korea seeks to accelerate 'smart defense innovation', 2021).

7.2.3 Artificial Intelligence

As an ICT powerhouse, South Korea currently invests heavily in innovative technologies (5G network, AI and big data), and is putting its bid as a global contender in AI capabilities. Since 2016 the South Korea government started to develop national AI strategies and to commit to investments in AI R&D. Its long term goal is defined as: "Realising a Human-Centred Intelligent Information Society by exploiting the advantages of new technologies like AI".

Some of the big tech companies, like Samsung, SK Hynix and Naver are currently working on (International Trade Administration, 2021):
- On-Device AI (faster and green AI computation);
- AI Chip (overcome data-sharing constraints while adding new AI products and services);
- AI engines for speech/image recognition;
- AI machine learning platforms and algorithms;
- Monetization of AI (scaling innovation).

Also the military sector has been actively reinvigorated by the state efforts through AI technology, as it aims to have "a smaller, yet smarter military" (Ministry of National Defence, Republic of Korea, 2021). A development plan is being established to apply AI to national defence in a systematic and strategic way. The development plan will include development strategies in all related fields, such as the creation of an ecosystem and AI ethics and culture. The MND also plans to improve the defence data management system, which is the basis for utilising AI, and to cultivate more specialists (Ministry of National Defence, Republic of Korea, 2021).

South Korean AI applications in the military domain mainly focus on two areas: unmanned systems, cyber technologies and detection/recognition. South Korea has at least three core reasons for seeking to adopt unmanned systems into its military. First, the reach of these platforms into complex terrains such as the high and steep mountains of the Korean peninsula, can provide better surveillance and reduce miscalculation when conflict occurs. Second, South Korea's neighbours, including North Korea, have already been operating unmanned systems and swarms. In 2014 and 2016, North Korean UAVs were spotted intruding into South Korean airspace (Ahn, 2016). Third, UAVs can be used to counter North Korea's non-nuclear provocations without human casualties. Another domain to which South Korea has paid particular focus is cyberwarfare. This is in large part due to the frequent cyberattacks that the country has faced, which have been linked to North Korea both through official government channels and via technology and software companies (Park, 2018). To prevent and counter cyberattacks, South Korea is considering development of AI-based means (combination of big data and deep learning techniques) for early detection and response to cyberthreats (South Korean National Security Office, 2019). Within the Agency for Defence Development a focus area of AI is detection and recognition. ADD is currently conducting research on acoustic recognition, object recognition from satellite imagery, and TEL (Transporter Erector Launcher) recognition and is actively developing embedded AI (Tiny AI) devices (ADD - Agency for Defense Development, sd).

Both the MND and the defence industry sector have launched several initiatives to boost AI for military applications. At the beginning of 2019, the South Korean Army launched an Artificial Intelligence Research and Development Center (Dominguez, RoKAF to launch AI research centre, 2018). The short-term aim of this centre is to build the vision and concept for military applications of AI and to develop the next generation of combat power. In 2018 the Korea Advanced Institute of Science and Technology (KAIST), one of the world's leading research universities, started to team up with Hanwha Systems (Ji-hye, 2018), the defence business unit of Hanwha Group, to research and develop military AI-based systems. Their cooperation on military AI technology includes four projects: navigation algorithms for large-scale unmanned underwater vehicles (UUVs), AI-based command systems, AI-based aviation training systems and AI-based object-tracking techniques.

However, despite the aforementioned initiatives and activities the defence area is, compared to the private sector, still lagging behind in terms of its capabilities to use Industry 4.0 technologies, such as AI, big data, and the Internet of Things (IoT). This is due to various restrictions that have prevented defence innovation using advanced technologies (Yoon J. , 2021).

7.2.4 Cyber & EM

South Korea is one of the most digitally connected countries in the world. Like other digital societies, it is vulnerable to cyber-attacks. Cyber-attacks suspected of originating from North Korea, in particular, have become increasingly sophisticated. North Korea has used cyber-attacks to achieve its political goals in South Korea by stealing information and mlns of dollars, sowing a sense of vulnerability in Korean society. Attacks from North Korea and other malicious actors have disrupted information and communications technology (ICT) systems in the South Korean government and the country's private sector.
In April 2019 the National Cybersecurity Strategy was published (Security, sd). The strategy did not specifically address technology investments. The strategy mainly focusses on organisational structures and processes.

The Defence White paper 2020 states the MND's plans to enhance its capability to effectively respond to unstructured cyber-attacks with the help of the latest technologies including AI and to continuously reinforce the functions and performance of the cyber-operation system. The latter is addressed as the "cyber-operation situation visualisation system". Also, the use of modelling and simulation to periodically conduct cyber-simulated training and exercise is a priority.

South Korea has stepped up the development and manufacture of maritime EW systems and is installing them on its naval vessels to combat ongoing threats from North Korea. The effort includes the development of South Korea's first EW system for a submarine (Kim F. , South Korea increases use of electronic warfare systems at sea to counter North Korean threats, 2021).

As part of the substantial investments in Space capabilities (see 7.2.9) systems for anti-electronic warfare satellite transponders will be developed (Yonhap News Agency, 2021). Due to increased threats against satellites aiming at degradation or denial of satellites services, it is important to protect satellite transponders against advanced EW techniques like jamming.

Intelligent self-learning-based autonomous jamming technology is being researched by the Agency for Defence Development. This technology is intended to respond to environmental changes in the future battlefields and North Korea's missile threats (ADD - Agency for Defense Development, sd).

7.2.5 Quantum

In 2019 South Korea started a five-year development programme for quantum computing technology. This national quantum computing research programme includes:

- Investment of 39.7 mln USD for 5 years to develop core technology of quantum computing and to expand research base.
- Investment of 11.9 mln USD in next-generation ICT technology including ultra-high-performance computing knowledge data convergence, system software, software engineering, information and intelligence systems, and HCI (Human-Computer Interaction).

Through the development of key technologies for quantum computing, the government plans to complete demonstration of a practical five-qubit quantum computer system with more than 90% reliability by 2023 (QURECA, 2021).

According to the Korean Agency for Technology and Standards (KATS), a government agency that leads national standards and technical evaluation, South Korea has secured an advantageous position in leading the international standardization of quantum information technology, which will have a profound impact on information and communications technology networks (Chang-won, 2020).

The Agency for Defence Development is conducting research on atomic technology which relates to the principles of quantum mechanics. Using the quantised internal energy levels of atoms, Atomic Technology is able to accurately measure physical quantities of objects. Probing the 'Larmor Precession' of quantised atomic spins for accurate measurements of rotational quantities, the Atomic Technology enables long-term quantum navigations under GPS-free environments.

However, as far as we know based on public information, the MND is no partner in national quantum research programmes, although the MND states that it aims to utilise civilian R&D quantum research and capabilities.

7.2.6 Sensor

To improve Korean missile defensive capabilities to respond to provocations, such as through ballistic missiles and long-range artillery, strengthening of capabilities will be conducted in sensors for detection, C2 and interceptors. This will involve additional force integration of an early warning radar with improved detection range capabilities, and significant improvement of the target handling capabilities by upgrading the performance of 'Korea Theater Missile Operation Cell,' which plays a core role in responding to ballistic missiles.

The Army will develop a further miniaturised counterbattery detection radar. Due to North Korean artillery threats a miniaturised and mobile radar will be able to detect artillery projectiles fired by howitzers, mortars or rocket launchers and, from their trajectories, be able to locate the position on the ground of the weapon that fired it (Young-bin, 2021).

To improve battlefield visualisation and day and night surveillance capabilities the army will be provided with Recce-UAVs, advanced thermal observation devices, multi-functional observation devices and multi-source video convergence systems (Ministry of National Defence, Republic of Korea, 2021).

In close cooperation with the civil sector ground-penetrating radar systems will be developed. The civil application and interest is based on detection of remains and the many ground subsidence accidents that have happened in Korea (leakage of underground pipes e.g.). The military interest is related to the detection of explosives and mines (Ministry of National Defence, Republic of Korea, 2021).

When it comes to the threat coming from North Korea, most eyes are on nuclear weapons and conventional missile attacks. However, the South Korean government also has its eyes on chemical and biological attacks, particularly employed by terrorists. Therefore CBRN protection, detection and identification capabilities are strengthened by field deploying new capabilities using cutting-edge technology (Ministry of National Defence, Republic of Korea, 2021). It remains unclear what these technologies are, since nothing about that can be found in open sources.

The Agency for Defence Development is conducting research on elementary photonic radar technology. Photonic Radar comes from the fusion of photon-based signal source generation and radiofrequency radar, which enables higher resolution and signal-to-noise ratio compared to those of the existing radar systems. It intends to reinforce capabilities to detect multiple threats with precision which are becoming smaller in size and stealthier.

7.2.7 Man-machine integration

One of the key national technology projects on man-machine interaction is the ExoBrain project which started in 2014 with funding from the Ministries of Science and ICT. It is planned for nine years and the total budget is $90 mln. The ExoBrain consortium consists of national research institutes (ETRI and KITECH), companies and universities. The goal is to develop natural language dialogue systems for knowledge communications between humans and machines in specific domains (Exobrain, sd).

KAIST is one of the global leading universities in robots and in Human-Robot Interaction technologies. Although there was a controversy in 2018, blaming KAIST of working together with national defence industry on the development of killer robots, KAIST stated that it would solely develop technology that comply to the UN rights declaration (Haas, 2018). Nevertheless, one may assume that advanced concepts of human-robot teaming and man-machine integration will de dually used (civil and military) in South Korea.

A specific example of a human-robot teaming project is the HUAIS-Project. Korea Aerospace Industries (KAI) is gearing up to develop a manned-unmanned teaming (MUM-T) military platform, named the Helicopter-Unmanned Aircraft Interworking System (HUAIS) Project. The project, announced on 28th October 2021, aims to set up a manned-unmanned teaming system that allows a helicopter pilot to directly control the unmanned air systems in order to provide image information acquired by the unmanned air systems to the helicopter pilot in real time. By this the operational radius of the combat helicopter is expanded (Min-hee, 2021).

7.2.8 Weapons

In the medium-term plan 2019-2023 it was decided to substantially increase the defence budget in order to secure the South Korean military’s core capabilities to respond to nuclear and WMD (weapons of mass destruction) threats and to take OPCON (operational control). The extra budget allocation also aims to build strategic deterrence capabilities which enable the South Korean military to respond to comprehensive and omnidirectional threats (Ji, 2019).

These capabilities include a “Korean-style missile defence capability” by improving the performance of early warning radars for the detection of ballistic missiles, the Air and Missile Defence Cell (AMD–Cell), and the Cheolmae-2 medium-range surface-to-air missile (KM-SAM). It further includes the creation of an Iron-Dome interceptor system against North Korean artillery (Yonhap News Agency, 2021). This will enable South Korea to defend its capital and key infrastructure throughout the country. Additionally, South Korea will acquire new submarine-launched ballistic missiles (SLBMs) to protect it from North Korea’s nuclear-powered submarines (Dominguez, South Korea conducts SLBM test from underwater barge, 2021). Because South Korea cannot create nuclear weapons, the government must actively expand its anti-missile capabilities to deter North Korean.

Seoul’s missile activities have long been constrained by decades-old limits that South Korea agreed on with its longtime ally, the United States. At various junctures, these limits have gradually been loosened and from 2020 on South Korean individuals and entities are, for the first time, capable of developing, producing, and possessing space launch vehicles making use of solid rocket motors without restrictions. Despite these guidelines South Korea has been able to develop very advanced weapon technology. An example is the Hyunmoo-4 ballistic missile equipped with a very heavy warhead (Panda, 2020). Currently South Korea is also doing research on hypersonic weapon technology. It aims to start testing a prototype for a ground-launched hypersonic cruise missile in 2022. It is equipped with a two-stage rocket booster and is under development by ADD and Hanwha industry. The in-service date is planned in 2026 (Kim M. , 2021).

In addition, the introduction of stealth fighters will be completed which provides effective deterrence capabilities against potential threats, as well as nuclear missiles. It also will improve rapid and long range precision strike capabilities against strategic targets by diversifying the means of striking, such as transporter erector launchers (TEL) (Ministry of National Defence, Republic of Korea, 2021).

For the ground forces, the MND will strive for an early expansion of highly powerful and ultra-precision ground-to-ground missile forces (Ministry of National Defence, Republic of Korea, 2021).

In preparation for the threat of drone terrorism, the ministry of national defence is conducting R&D activities to secure anti-drone capabilities such as anti-aircraft laser weapons (Ministry of National Defence, Republic of Korea, 2021).

South Korea also starts to work on loitering ammunition. Korea Aerospace Industries has recently started a cooperation with Israel Aerospace Industries on a loitering munitions programme for maximising the effectiveness of strike missions against enemy air defences (Kim B. , Israel and South Korea to boost collaboration on loitering munitions, 2021).

7.2.9 Space

Commercial space projects in South Korea have seen tangible progress, with the country launching its homegrown, three-stage Nuri rocket, a $1.8 bn project designed to put a 1.5-ton satellite into orbit about 600-800 kilometres above the Earth this year. But there is also much space activity in the military domain.

An ambition on the short term is to launch 110 dual-use satellites. Among the 110 small satellites are reconnaissance versions for military purposes; communications satellites for testing 6G broadband internet; and observation satellites for monitoring space weather.

In august 2021 South Korea announced the establishment of a task force to further develop space capabilities for its military (Kim B. , With restrictions lifted, South Korea launches $13B space power scheme, 2021), following US approval earlier this year to lift a restriction on the country’s missile production programme. The South Korean Defence Acquisition Programme Administration (DAPA) agency endorsed a plan to invest nearly $13 bn over the next decade to help local industries develop technologies for military satellites. To that end, the Agency for Defence Development decided to transfer core satellite technologies to local defence contractors in preparation for the mass production of military satellites.

A key capability for the military will be the development of a ‘24-hour monitoring system’ against threats, in order to strengthen its omnidirectional threat deterrence capabilities. This will involve the force integration of spy satellites for military use, and the development of a micro-satellite reconnaissance system (Young-bin, 2021).

The MND also plans to develop a high-powered laser satellite tracking system and a radar space surveillance system, in order to surveil and respond to space-based threats (Young-bin, 2021).

On the longer term South Korea has set off on a journey to build its own satellite navigation system, in cooperation with the United States, by 2035 to provide more accurate and reliable position, navigation and timing information across the country. The first satellite for KPS will be launched in 2027, with a trial service scheduled for 2034 and a full-fledged one the following year. The KPS, when established, will make South Korea the seventh nation in the world to have its own satellite-based positioning, navigation and timing system, after the US, Russia, Europe, China, India and Japan. Its coverage encompasses Southeast Asia, Australia and New Zealand (Si-soo, 2021).

7.2.10 *3D printing and new materials*

Korean government is trying to find new growth engines for economy through the fourth industrial revolution. One of the key technologies for the fourth industrial revolution is the development of 3D printing technologies. As the country is still heavily relied on manufacturing sector for its economic growth, it is very important for Koreans to innovate in the manufacturing process in order to be competitive in the world market. One of the sectors in which 3D printing is foreseen to ensure growth is the Marine sector. However, among all sectors in 3D printing industries, Korea stands out in the medical and bio sector (Eun Ha, 2018).

3D printing is becoming central to South Korea’s defence industry, with thousands of parts printed each year for the Ministry of National Defence, including components of the indigenously manufactured KF-21 fighter jet. The MND has configured a new division devoted to 3D printing for defence. It consists of two units: one specialised in improving existing military goods and one focused on future products (Kim F. , Republic of Korea military turns to 3D printing for supply chain reliability, 2021).

3D printing technology will also be Utilised for better fitting combat uniforms. Currently size measurement using "3D scanning" is in use as a pilot project for servicemembers in training centers to provide clothing and personal equipment suitable for the actual body size of each soldier. The next step would be to link the 3D scanning to 3D printers in order to produce tailor-made uniforms (Ministry of National Defence, Republic of Korea, 2021).

With respect to technology development and applications of metamaterials in the military no valuable information has been retrieved from open sources. However, in South Korean’s academic world some interesting successes have been claimed with potential military applications. One refers to a ‘fluid invisibility cloak’. A team of South Korean scientists extended the concept of a metamaterial and applied it to hydrodynamics. Compressing coordinate spaces around a specific space will make the space in the middle empty and a fluid will move in the same flow even if it encounters an obstacle. Objects placed in such an empty space are not subject to flowing drag force and can move without resistance as if they were moving in vacuum. Therefore, the metamaterial is expected to reduce fuel consumption and noise caused by fluid friction and move at higher speed than before if it is applied to airplanes, missiles and submarines among others (Eun-jin, 2019).

7.2.11 *Biotechnology*

The Korean government is determined to nurture the bio-health sector as one of the future growth engines. The goal of this plan is to increase the worldwide market share of Korean pharmaceutical and medical devices from 1.8% in 2019 to more than 6% by 2030 (Biotechnology Innovation Organization, 2021). As one of the leading and successful countries in fighting the COVID-19 pandemic, South Korea is planning to acquire technology to respond to new infectious diseases. Other areas of research and development include regenerative medicines to strengthen research in stem cell technology, next-generation biotech (such as single-cell analysis) and brain-related research (Yonhap, 2020).

South Korea has also be(en) one of the front runners in research and development in genetics and cloning, with the first successful cloning of a dog in 2005 and the cloning of two females of an endangered species of wolves by the Seoul National University in 2007 (Reuters, 2007). However, the rapid growth and progress of the biotech industry has resulted in significant voids in regulation of ethics, as was highlighted by the scientific misconduct case involving Hwang Woo-Suk (Cyranoski & Check, 2005).

The Agency for Defence Development is applying synthetic biology technologies on genome-analysis-based siRNA research for hantaan virus or SARS-CoV-2 as well as on DNA vaccine researches (ADD - Agency for Defense Development, sd). Further it is unknown (based on the opens sources that have been checked) if other biotechnology developments have or will reach the military domain. The only cue in such a direction is the US military facility in Busan’s port (presumably a joint facility with South Korea) where the US operates a bio-surveillance project, dubbed JUPITR ATD for “Joint United States Forces Korea Portal and Integrated Threat Recognition Advanced Technology Demonstration.” While JUPITR’s stated aim is the development of early-warning detection capabilities to protect the USFK and South Korea from biological and chemical threats, it has been the subject of constant criticism since 2015 (He-rim, 2019).

7.2.12 Simulation and virtualisation

With the demographic challenge in mind, resulting in a smaller military work force, the MND plans to fully exploit the advantages of simulation technology. One of the key ambitions is to embrace LVCG (Live, Virtual, Constructive, Gaming) for unit training and joint exercises (Ministry of National Defence, Republic of Korea, 2021).

The MND also plans to operate a realistic training system by applying Virtual Reality (VR) technologies. With the consideration of battlefield environments and the characteristics of each Armed Forces branch’s missions, it will create the “special operations simulation training system” for the Army, the “submarine crew training system” for the Navy, and the “air base operation training system” for the Air Force. In addition, the development of the education programme for the maintenance of military equipment, which involves safety risks and requires a high level of technical proficiency, as well as a system that supports actual maintenance activities are underway. The VR-assisted training system is expected to contribute to accident prevention and budget reduction (Ministry of National Defence, Republic of Korea, 2021).

In order to better prepare the large reserve forces, scientific reserve forces training centres have been built. These centres provide urban combat training in a very realistic simulation setting, automated indoor shooting ranges and training management systems which manage the entire training courses realtime from admission to discharge of reserves. To be cost-effective the training centers will be open on weekends when there is no training to make the space available to local residents, such as security field trips (Ministry of National Defence, Republic of Korea, 2021).

7.2.13 Human Performance and Training

One of the key defence projects on physically and cognitively strengthening the military is the "warrior platform". It will upgrade the equipment of individual troops to increase their survivability and enhance their combat abilities, turning them into "cutting-edge scientific technology soldiers," as described by former Army Chief of Staff Gen. Kim Yong-woo at a press conference in February 2019. Such equipment includes a ballistic helmet, combat and night vision goggles and an infrared designator used to distinguish friend from foe (Lee M. , 2021).

In order to prevent unnecessary and too long physical strain on soldiers the introduction of robots for operational sustainability support is promoted. Robots will be used to solve fatigue problems caused by the reduction of human resources and heavy weight and repetitive work. Currently a pilot of muscle-assisted robots in the ammunition and engineering units of the Army is conducted (Ministry of National Defence, Republic of Korea, 2021).

The MND is going to Utilise big data for improving safety and health of the military. This relates to food, clothing, and medical care. Regarding food, the MND has established an optimal food demand prediction system. In the medical field, a mobile remote diagnosis and treatment system is being established that enables quick response by sharing the information on emergency patients being transferred with the Medical All-Source Situation Center in real time. An analysis system that can support the decision making of medical staff with the use of military medical big data is also being facilitated. For measuring training progress the “Smart Trainee Management System” within the Korea Army Training Center will be developed. It facilitates the real-time assessment of education and training by using wearable devices to manage trainees’ health data (Ministry of National Defence, Republic of Korea, 2021).

The MND also stresses the importance of strengthening the spiritual and mental abilities of the military. By switching from the existing lecture and discussion-oriented education to a hands-on, self-directed education, the individual soldiers themselves are able to establish mental preparedness and enhance their inner growth and pride in military service. The latter is strengthened by improving historical knowledge, e.g. indirectly access historical sites through mission-oriented educational content and a "soldierly mindset in movies" programme (Ministry of National Defence, Republic of Korea, 2021).

7.2.14 Robotics and Autonomous systems

To compensate for its decreasing work force, to enhance the survivability of the force and to transform the military in a smaller but more intelligent and advanced force, the introduction of unmanned and autonomous systems is prioritised. In all domains there are plenty of efforts ongoing in this area, as we see in some of the examples below.

South Korea’s borders are on the verge of becoming protected by an “AI-based surveillance systems,” a technology known as the Mobile Rail Robot Surveillance System, which moves along a rail at a speed of five miles per hour (Dominguez & Cazalet, South Korea to deploy rail-mounted robot, AI-based surveillance systems to enhance border security, 2021). In addition to the AI-based surveillance systems, the MND purchased three types of unmanned aerial vehicles (UAVs) –

"suicide drones, an attack drone armed with a rifle, and a small-sized drone for reconnaissance and offensive operations" from local defence contractors. Obtaining UAVs and drones adheres to improve South Korea's defence capabilities, and also to counter against North Korean drones (Kim B. , South Korea accelerates deployment of unmanned systems, 2020).

High-altitude and middle-altitude unmanned aerial vehicles will be employed to conduct 24-hour monitoring by obtaining video information on the Korean Peninsula area. This capability is part of the 24-hour monitoring system' against threats, in order to strengthen its omnidirectional threat deterrence capabilities. This will, next to UAVs, also involve the force integration of satellites for military use (Young-bin, 2021).

In 2018, the army installed the Dronebot Jeontudan Unit (Jae-in, 2017). The primary purpose of this unit is to carry out reconnaissance tasks targeting North Korea's nuclear and missile sites. It could also launch swarm attacks in the event of a conflict. And there is more to come. The Army will start testing a new combat system in 2024 to guide its entire operations as early as 2040. "The Army Tiger 4.0, which is short for "Transformative Innovation of Ground forces Enhanced by the 4th industrial Revolution technology" is believed to be the future of warfare delivered by cutting-edge advances in technology. This system will employ artificial intelligence-powered drones to facilitate decision-making on the battlefield, and use highly mobile armoured fighting vehicles that will be run by soldiers in advanced combat gear (Si-young, 2021).

The system, which is de facto a manned and unmanned hybrid combat system, must gain operational advantages, like improved ground and air manoeuvrability due to rapid response and decisive operational execution (Ministry of National Defence, Republic of Korea, 2021).

In the logistics domain the introduction of transportation drones is foreseen. The primary usage will be to provide quick support to remote and isolated units which are restricted from access during contingencies. Currently, the MND is conducting preliminary research on drones for transporting military supplies, evaluating the Utilisation of excellent commercial drones, and promoting technical cooperation projects for both civilian and military use (Ministry of National Defence, Republic of Korea, 2021).

The Agency for Defence Development is even working on next level robotics, being biomimetic robots. This refers to a robot with an engineering system based on structures, mechanism, and behaviours found in various living organisms.

Up to now, biomimetic robots have been studied to simulate the motional characteristics of insects, fish, reptiles, and quadrupeds. Studies related to simulating organisms' sense organs, ways of communication, and behavioural controls are in progress (ADD - Agency for Defense Development, sd).

7.2.15 ICT and networks

MND's overarching goal is to create a super converged defence infrastructure that connects defence resources with infrastructure similar to neural networks. Advancement projects are being carried out in network infrastructure environments such as building the next-generation military broadband convergence network and forming defence mobile and cloud environment. In order to ensure the security and flexibility of wireless data communications in line with the creation of a super-connected defence environment, various development measures are also being promoted to improve the wireless encryption policy (Ministry of National Defence, Republic of Korea, 2021).

The improvement of ISR capabilities will be established by the "Intelligent ICT Surveillance and Reconnaissance System" that is capable of combining and analysing the imagery intelligence obtained from various sensors like military satellites, reconnaissance aircraft, and UAVs. The long term plan is to develop an AI-based intelligent C2 system, utilise the system to analyse and share battlefield situations in real time, and, thus ensure rapid command and control (Ministry of National Defence, Republic of Korea, 2018).

On the short term, the MND will continue to secure high-speed, high-volume information distribution capabilities and enhance interoperability during combined and joint operations through upgrading joint tactical data links, air-to-ground communications radios, and Link-16 (Ministry of National Defence, Republic of Korea, 2021). A technology that is being researched for that purpose is Terahertz technology. The Agency for Defence Development conducts research on terahertz signal source generation and radio detection technologies. Next to realising high-speed/high-capacity communication technology Terahertz technology is also capable to provide all-weather surveillance (ADD - Agency for Defense Development, sd).

Future battlefield is evolving from Network Centric Warfare based on centralised sequential kill-chains, to Mosaic Warfare based on distributed adaptive kill-webs.

The Agency for Defence Development is looking into the concept and principles of Mosaic Warfare. In multi-domain and multi-dimensional operations, Mosaic Warfare strives to accomplish a force package with decentralising friendly forces (risk distribution) to maximise survivability and with mission-focused lethality to adversaries. There, individual warfighting platforms on distributed adaptive kill-webs are put together in faster, flexible, and adaptive ways driven by the 4th industrial revolution technology. ADD's work is aimed to prepare the Korean forces for future omnidirectional threats by constructing K(orean)-Mosaic Warfare based on the advanced defense S&T such as unmanned, autonomy, intelligence, and swarm technologies.

However, currently, South Korea's existing operational concepts are single domain, limited to a single service's responsibility, and purely defensive. A transformation to multi domain operations and mosaic warfare would pose an additional challenge with respect to C2. A wartime OPCON transfer from the US to the South Korean military is envisaged but not yet decided. This would require a clear decision: either continuing the ongoing development project for an indigenous C2 structure for South Korean military or model the South Korean C2 system on the US Joint All-Domain C2 system, to facilitate compatibility between the two militaries (Yoon S. , 2021).

7.2.16 Behavioural engineering

If zooming in on disinformation, which is only one element of behavioural engineering, then South Korea faces a low trust in media. According to the latest annual study by the Reuters Institute at the University of Oxford, just 32% of South Koreans trust the media. That is among the lowest of the 46 countries surveyed. As in other countries, social media has fractured the South Korean media landscape and deepened political divisions. After a political corruption scandal in 2017, many media followers shifted from the traditional media tot social media platforms like Youtube, which increased the amount of fake news and polarised online discussions and protests (Keller, 2020). Rumourmongering and manipulation of public opinion have meanwhile become key features of its politics.

Also the military has (had) its hand in disinformation. During the impeachment of ex-President Park Geun-hye in 2017, an internal investigation revealed that intelligence agents and military officials had engaged in political astroturfing to ensure Park's election victory in 2012. While the scope and influence of this campaign remains unclear, it is suspected that the National Intelligence Service mobilised approximately 3,500 social media accounts and posted some 275,000 defamatory messages about Park's opponents. Although psychological operations against North Korea are important, the abuse of disinformation by the military for national objectives, has backfired and put a brake on the military's influencing activities (Tworek & Lee, 2021).

Despite its history of wide use of psychological operations during the Korean War, there is no actual information and indication that this area of expertise is currently highly developed within the armed forces. Since the neuroscience and behaviour academic field in South Korea is moderate, no single university is included in the various top-100 lists (U.S. News, sd), a boost from the academic field towards military applications doesn't seem very likely.

7.2.17 Energy

In 2018, South Korea had the lowest share of energy from renewable sources in energy supply among all member countries of the IEA (International Energy Agency). The Korean government is determined to change that. In July 2020, South Korea announced its Green New Deal, which targets an increase in the share of renewable electricity to 20% by 2030 and up to 42% by 2034. One of the technology spearheads is the use of hydrogen fuel cells (Tachev, 2021).

From the sources we tried to find about military renewable energy applications and technology developments, it is not clear to what extent the green deal will also support the armed forces to incorporate energy technologies.

Some niches (ADD - Agency for Defense Development, sd) that are researched by e.g. the Agency for Defence Development are:

- *Perovskite Solar Cells*: Compared to other semiconductor based solar cells, Perovskite Solar Cells are capable of achieving the highest power per weight ratio as ultralight solar cells. There is no degradation of efficiency under varying incident angles of light, low temperatures, and even cosmic radiation. Perovskite Solar Cells can be used as the power source in combat suits and unmanned aerial vehicles carrying out long-endurance flight missions, etc.

- *Self-generated electrostatic energy*: This is a technology that harvests static electricity generated by friction between two objects and converts them into usable electrical energy, which can be used as an energy source for sensors or personal portable electronic devices.
- *Water battery technology*: This technology overcomes the limitations of existing lithium ion batteries and the limitations of using commercial high-efficiency fuel cells, enabling continuous and stable power supply in military systems and unmanned systems.

7.3 Official sources

The table below shows the official (MOD) sources that have been consulted. All other information is retrieved from sources not published by the MOD.

Title	Comments	References
Defence White paper 2020	The 2020 Defence White Paper contains the key achievements in the field of defence over the past two years and the future policy direction to thoroughly inform the public of such efforts of the South Korean Armed Forces.	https://www.mnd.go.kr/ (Ministry of National Defence, Republic of Korea, 2021)
2022-2026 Mid-term Defence Plan	The annually prepared midterm plans contain financial investment plans for the development and maintenance of the ROK armed forces over the next five years.	https://www.mnd.go.kr/ [recent news 15 Sep 2021]
ADD (Agency for Defense Development)	ADD is the South Korean national agency for research and development in defence technology. Its purpose is to improve the national R&D capacity, and to foster the domestic defence industry.	https://www.add.re.kr/
DAPA (Defence Acquisition Program Administration)	DAPA is in charge of improving the defence capabilities of South Korea, providing military supplies and fostering the defence industry.	http://www.dapa.go.kr/
KIDA (Korean Institute for Defence Analysis)	KIDA is a government-funded research institute that addresses a wide range of defence issues concerning the Korean Peninsula.	https://www.kida.re.kr/

8 Conclusions and recommendations

The conclusions are presented in four parts. First, the key findings as a result of the selection process of the referent countries, as well as the difficulties associated with the assessment process, are discussed. The following part answers the research questions that were posed in chapter 2, that culminate in the key takeaways of the benchmark. The third part briefly presents an overview of the findings on different innovation cultures. Lastly, the chapter ends with three recommendations.

8.1 Selection and assessment methodology

The most notable findings regarding the selection and assessment process are:

- Most of the non-EU/NATO countries that score high on criteria indicating the potential for developing advanced military technologies, are Asia-based. In particular China, India, Japan and South Korea score well on the Global Fire Power Index, on military expenditures and on an high-quality academic and industrial base.

- The open source information that was retrieved for the selected countries (India, Israel, Russia and South Korea) proved to be sufficient to continue the benchmark exercise. Nevertheless we encountered some difficulties as many official documents were only available in the local languages. There were also differences in the quality and level of detail of the sources between countries and also between technology areas. In general for both Israel and Russia the amount and in-depthness of the information was richer than for India and South Korea. This is probably the case, because Israel and Russia get more attention internationally and thus more sources were available and translated. However, also for them we could not always find specific information on certain sensitive areas, such as EW (Russia), soft-cyber capabilities (Israel) or behavioural engineering (Israel).

- The timeframe of our technology focus was between now and 15 years in the future, which implies that we looked for technology plans and ambitions which could be realised by 2035. However, most of the retrieved information related to capability investments and plans focusses on the short term (within 5 years). Technology and innovation ambitions on the longer term were often described in rather general terms. Therefore it was difficult to determine investment priorities for the longer term (2030-2035) and as a result, we could not use quantitative data (investments in money) but we had to shift to more qualitative data / judgements in terms of policy, ambitions and focus descriptions related to the technologies.

8.2 Technology takeaways

This subchapter answers the following four research questions:
1 To what degree do the four selected referent countries invest and innovate in the fifteen SKIA technology areas?
2 How much priority does each referent country individually give to each technology area?

3 If this is mutually compared between the four countries, what stands out? Are there for example technology areas that receive an above or below average amount of attention in multiple countries?
4 Are there (sub)technology areas other than the fifteen highlighted SKIA areas in which (one or more of) the referent countries have an interest?

Investments and priorities
By using scores for each technology area, we assessed if a country is investing less or more in this technology area than in the other technology areas. In the figure below an overview of these scores is presented, indicating how much priority each technology area receives per benchmark country. A score of 1 implies very low priority, while a score of 5 implies very high priority. [33,34]

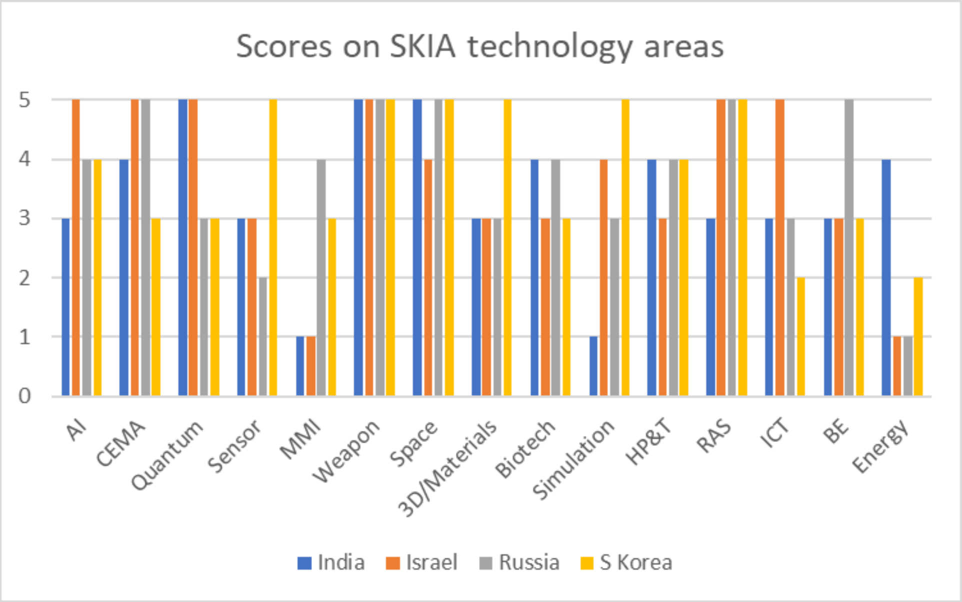

Figure 6 Total benchmark scores.

Observations derived from the scores are:

- All 15 SKIA technology areas are given moderate to high attention by at least two of the benchmark countries (with the exception of Energy, even though it is quite highly prioritised by India), which leads to the conclusion that these 15 areas are a firm and well substantiated choice.

- Weapon, Space and RAS are technology areas that get a high priority in most countries. CEMA and Quantum are highly prioritised in two out of four countries, and moderate to high by the rest. Also, AI scores relatively high, with only India giving it moderate attention. This is not a big surprise since these technology areas are generally considered to be the most disruptive ones.

[33] The indicators have been converted to numbers: -=1, -/0=2, 0=3, 0/+=4 and +=5
[34] Be aware that the scores represent relative values within a single country. E.g. a 5 score for Israel does NOT imply that Israel spends more money than Russia on AI (Russia getting a 4 score), but it implies that AI is one of the top priorities in Israel while in Russia AI is important but is a lesser priority than Space and Weapons.

- Man-Machine Integration (MMI) and Energy score relatively low. For Energy it can be explained by the fact that most countries do not consider this as a high military priority yet, as most of the investments go to 'hard' technologies like weapons and platforms/systems. The low score on MMI is more difficult to clarify when compared to the high scoring technology areas AI and RAS. The only explanation we can offer is that MMI innovations are often indirectly included in AI and RAS.

- Behavioural Engineering (BE) scores average for all countries except for Russia where it has gotten a high score. The reason is most information that was found, was focused on influencing (the behaviour of) populations via for example social media. The use of psychological operations developments within the military context are difficult to gather via open source information. However, since we can safely assume that at least to some degree investments are being made in this domain, all countries were given medium scores. Russia on the other hand has gotten a lot of public attention for amongst others its 'Maskirovka' efforts. Based on that information, it can be concluded that this country gives BE a high priority compared to other technology areas.

Takeaways per country

- India gives relatively low priority to simulation & virtualisation, and scores modestly on RAS. The latter is probably due to their current modest developments in the area of AI. On the other hand, India gives relatively high priority to quantum technology and energy. India is starting to align quantum research initiatives in both the defence and civil domain, which is financially boosted in recent years. India's good ranking in energy is due to India's global co-leading position in solar energy and battery storage.

- Israel gives ICT a high priority, which is not surprising due to the country's advanced intelligence capabilities and high degree of integration between their armed forces (in particular land, air and special operations forces) which requires advanced C4I capabilities. The lower score for space (when compared to the other countries) can be explained, because it is relatively the other technology areas in which Israel invests enormously in. With regard to the peculiar score of BE, we could not find sufficient information to assess Israel's behavioural engineering investments. So it might be that this area is indeed relatively lacking behind compared to the others, or that Israel is less transparent in their priorities and investments in this area.

- For Russia three areas are stand out. The two that are relatively high prioritised are BE and MMI. Russia makes extensive use of BE, considering their expertise and the emphasis they put on deception and disinformation. With regards to MMI, Russia is one of the three nations (besides China and the US) that is almost done with the development of human-AI teams, which has serious future potential. Sensor technology however scores relatively low, since sensors are a notably weak component of the Russian armed forces. Also energy scores quite low. Russia is an exporter of traditional energy sources and is therefore not very eager to invest in renewable energy, also not in the military domain.

- South Korea gives high priority to simulation & virtualisation due to its substantial decrease in military manpower on the short term. Also 3D printing scores relatively high, since 3D printing is becoming central to South Korea's defence industry. And due to the constant missile threat from North Korea investments in sensors have been substantial, which explains the sensor score. Remarkable is the low score on ICT, since the civilian ICT sector in South Korea is amongst the global leaders. The shortfall on ICT is seen in the low level of horizontal integration between the armed forces.

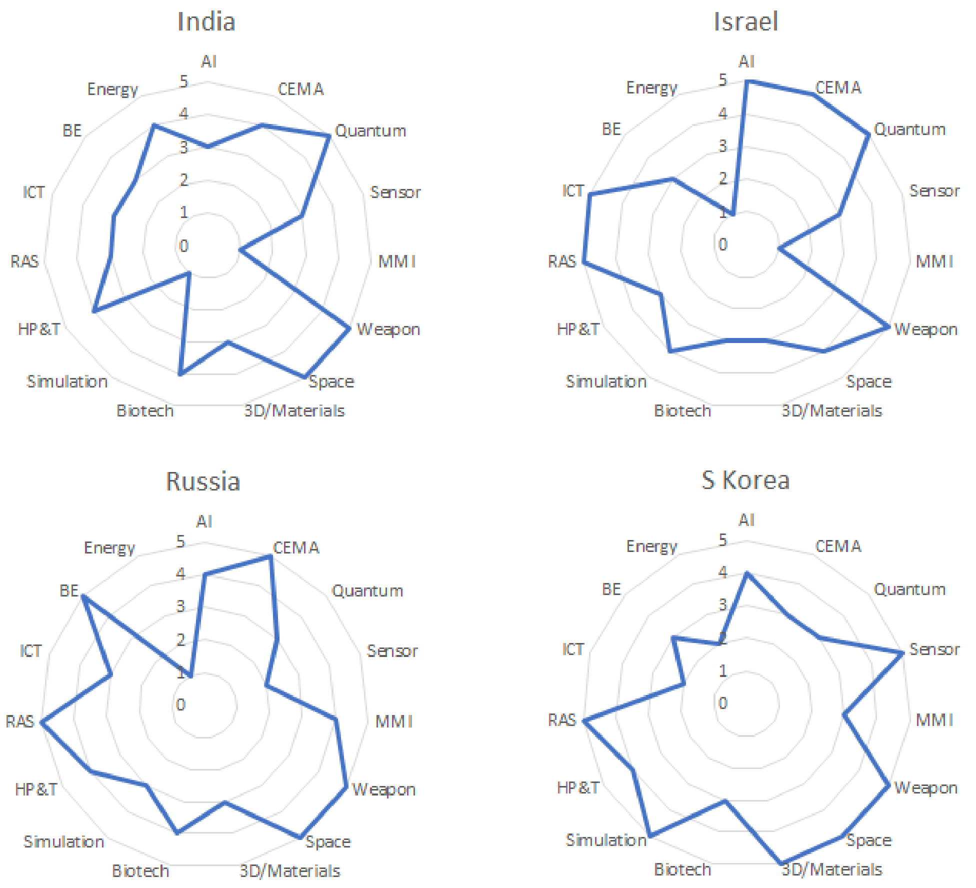

Figure 7 Benchmark scores in individual spiderwebs.

In addition to the aforementioned observations regarding the different scores per country, some takeaways are provided in the table below. They summarise the most interesting findings with regard to plans, investments and activities in the 15 SKIA technology areas as well as in other (sub) areas.

Country	Most striking takeaways
India	• On AI and Cyber there are a lot of policy initiatives but the speed and strength of the Ministry of Defence's (MoD) innovation in AI and Cyber is lacking, making investments currently less effective. • Investments in quantum technologies, hypersonic weapons, directed energy weapons and space technology are considerable and puts India in the global chasing group after the US and China. • Geographical and environmental challenging conditions stimulate India to invest in science and technologies that improve or sustain performance and health care of the military.
Israel	• The Israelian Defence Forces have, probably more than other forces, expanded unconventional capacities and cyber and intelligence capacities, due to constant terrorism threats. • Israel is investing a lot in education, both in the civil and military sector, with a focus on amongst others cyber, biotech and fintech. The aim is to let the IDF benefit from it. • The Mossad's Technological Innovation Fund, focuses on two technology areas outside the SKIA technology scope: Financial Technology (Fintech) and Smart City Tech.
Russia	• Russia aims to close capability gaps vis-à-vis its strategic rivals through a combination of buying new systems and upgrading old ones, especially in relation to its artillery and manoeuvre forces. • The MoD wants the defence industry to convert 30% of its output to civilian and dual-use products by 2025, and 50% by 2030. • High focus on C2 Disorganisation (C2D), on creating a heavily CEMA-denied environment in combat operations, on Anti-Satellite weapons and on behavioural engineering, including using AI-enabled technology. • The Centre for the Fourth Industrial Revolution in Russia focuses, amongst many SKIA technology areas, also on one technology area unknown to the SKIA: Smart City Tech.
South Korea	• Due to scarcity of personnel the military force has to transform in a smaller but more intelligent-based force, therefore prioritising AI, autonomous systems and simulation technologies. • Due to the proxy threat of a North Korean rocket and missile attack, the MoD invests substantially in capabilities that improve the sensor-to-shooter chain (e.g. sensors, interceptors, C4I[35]). • Interesting 'niches' in which the MoD invests include the utilisation of big data for improving military safety and health and the improvement of mental and spiritual abilities.

Newly identified technologies and innovations

It should be noted that some technologies were identified that are not fully addressed by the SKIA Technology Watch. Although these technologies can be assigned to one or more SKIA technology areas, they still require additional attention and further analysis, because they appear to be 'odd ones'. They need more research, probably within TNO's yearly technology assessment. These newly identified (sub)technologies (in some case they are actually innovations) are listed in the table below.

[35] command, control, communications, computers, and intelligence

(Sub)technology / innovation	Description and military value
Fintech	Fintech (Financial Technology) could be used for military purposes. One example includes blockchain, which can prevent armed forces and their countries from cyber-attacks, defend critical weapon systems, manage automated systems, validate orders and information on the battlefield or manage supply chains and logistics.
Smart City	Smart City technologies include predominantly ICT and sensor technologies like IoT[36], smart and ubiquitous sensors. These are relevant for the defence domain, since a great deal of future warfare will be focused on the networked urban environment.
Atomic	Using the quantised internal energy levels of atoms, Atomic Technology is able to accurately measure physical quantities of objects. Atomic Technology enables long-term quantum navigations under GPS-free or denied environments.
Terahertz	The electromagnetic spectrum in the frequency range between 100 GHz and 10 THz is referred to as terahertz range. By using this spectrum it is possible to realise high-speed/high-capacity communication and to provide all-weather surveillance.
Photonic radar	Photonic radar is a technique/technology by which radar may be produced and analysed with the help of photonics rather than traditional radio frequency (RF) engineering techniques. The frequency of the radar is still in the RF, but lasers are used to create and analyse the RF signals with high precision. It intends to reinforce capabilities to detect multiple threats with precision which are becoming smaller in size and stealthier.
Biomaterial infused invisibility cloaks	Biobased material that bends light to make people and objects nearly invisible to the naked eye. Unlike traditional camouflage materials, which are limited to specific conditions such as forests or deserts, these invisibility cloak intend to work in any environment or season, at any time of day.
Underground (border) sensors	Sensors that collect both acoustic and seismic data, e.g. to detect subterranean tunnels or tunnel activities. These sensors are increasingly wireless and part of an interconnected network.
Anti-satellite weapons (ASAT)	Space weapons designed to incapacitate or destroy satellites for strategic or tactical purposes. ASAT roles include: defensive measures against an adversary's space-based and nuclear weapons, a force multiplier for a nuclear first strike, a countermeasure against anti-ballistic missile defence.

Innovation cultures and approaches
A few observations with regards to problems and solutions in innovation approaches were made that are interesting to the Netherlands as well:

- India, Russia and South Korea report a shortcoming of well-trained scientists and engineers in the high-tech domain. The South Korean MND claims that it can cope with it by transforming the military into a high-tech force and recruiting and/or engaging more civilian specialists, which probably will lead to recruitment competition with other sectors.
- Israel has an enormous innovative capacity. When looking at this country for inspiration, the solution lies in connecting the military to the civilian industry. Apart from Israel's specific context where every citizen has a military background, the country also invests a lot in education. This includes universities in general as well as offering educational opportunities within several MoD branches for applicants to be trained in the field of cyber. Also, investments are made in veterans to be schooled in e.g., cyber, biotech or fintech to continue with relevant innovative work that would benefit the MoD.

[36] Internet of Things

Increased civil-military cooperation makes the process of innovation more efficient and effective.
- All four countries have, although slightly differently organised, several innovation technology centres, where people with different specialist backgrounds as well as different industries come together to research and develop new technologies. This also fosters more civil-military cooperation (albeit there is enough budget and specialists available).

8.3 Recommendations

Since we did not have access to classified information and we only used English written documents, we need to be careful in drawing firm conclusions and identifying follow-up actions. However, some recommendations are applicable:

- Executing a benchmark of technology priorities for non-allied countries, operating in different geopolitical and threat environments, is valuable. It prevents tunnel vision and challenges to look for new opportunities and insights. Actively working on and maintaining databases of relevant sources related to global technology and innovation developments would smoothen and ease future benchmarking, and probably make it more cost-effective. If subject matter experts for specific countries could be linked up to both the process of maintaining a database and the actual benchmarking itself, the quality of the results would significantly improve.

- Although all 15 SKIA technology areas are well covered by one or more benchmark nations, some technologies and/or innovations within or related to these technology areas draw additional attention. Either because these get a rather high appraisal, more than one might expect, or because these are not yet covered within the Innovation Radar. The most striking ones are:
  - Biomaterial infused invisibility cloaks (see India);
  - Underground border sensors to detect subterranean tunnels (see Israel);
  - Anti-satellite weapons capability (see Russia);
  - Tools and methods to improve mental abilities (see India, South Korea);
  - Smart City technology (Israel, Russia);
  - Fintech (Israel).

  It is recommended to conduct more research on these areas, preferably combined with a brief impact assessment. An easy way to do so is to incorporate these technologies in the Innovation Radar, not yet as a substantial technology area but probably clustered in a few innovations that can be temporarily linked existing technology areas.

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A SKIA technology areas

Technology Areas	**Description**
Artificial Intelligence	Technology for realising cognitive and/or social skills of computers. Examples are pattern recognition, planning, learning, reasoning, explaining, decision support (cognitive), and social behavior and human-system dialogue (social). It concerns a very broad area that includes Machine Learning (ML) and Big Data analysis. Because ML is complex and data hungry, recent developments are focused on the automatic generation of ML models and the development of ML that can be trained with less data. Furthermore, powerful ML techniques such as Deep reinforcement learning (applied in AlphaGo Zero) are increasingly being used.
Cyber & Electromagnetic Activities	Technology aimed at strengthening the position of Defense in cyberspace (as the fifth operational domain) and the Electromagnetic spectrum (EMS). Development of methods, tools and resources in the following areas: (1) digital defence, (2) digital strike capability, (3) electronic warfare and (4) persistence. Offensive cyber capabilities and Electronic Warfare means of modern opponents are becoming increasingly sophisticated (including through the use of AI) and make a guaranteed and unimpeded use of the ICT infrastructure and the EM spectrum hardly possible.
Quantum	Technology based on specific phenomena from quantum physics (such as entanglement and superposition). It concerns the development of methods, tools and resources in the following areas (1) quantum computing, (2) quantum communication (incl. quantum key distribution), and (3) quantum sensing. Important developments are improving the stability of qubits, realising quantum communication over longer distances and with higher bit rates, and manufacturing new types of quantum sensors, e.g. for positioning.
Sensor	Technologies used for different types of sensors, with the aim of obtaining information about targets, environments and physical/physiological properties. Research topics include (1) radar, (2) underwater sensors, (3) (electro-)optical (EO) sensors, and (4) (micro/nano) sensors for specific (physical/physiological) measurements such as inspection of platforms. Developments concern real-time on-board (at the sensor) data processing, far-reaching autonomy of sensors (cognitive sensors), integration of heterogeneous sensors (radar, sonar, EO) and new sensor concepts (quantum sensor, smart dust).
Man Machine Integration	Development of methods, tools and resources aimed at optimising the collaboration between people and systems, especially AI-based systems. Traditionally, this has mainly concerned ergonomics and design of human-machine interfaces. Because systems are becoming increasingly intelligent but also increasingly form a 'black box', the current focus in developments is on improving (1) predictability, transparency, explainability of and trust in systems (2) how control can be kept over systems, and (3) social skills of systems.
Weapons	This concerns the deployment of new generation weapons, of which directed energy weapons and hypersonic weapons (at least five times the speed of sound: Mach 5 - 6200 km/h) are the most important developments. The aim of these developments is faster, more effective, more flexible (including dosable effects) and greater precision. Development of methods, tools and resources are in the following areas: (1) Laser weapons, (2) High Power Microwave (HPM) weapons, (3) boost-glide weapons, (4) scramjet weapons, and (5) hypersonic weapons.

Technology Areas	**Description**
Space	It concerns technology for the use of space through satellites and possibly also space weapons, as recent developments by major powers demonstrate. Development of methods, tools and resources in the following areas: (1) satellite observation, (2) satellite communications, and (3) space weapons. The most important developments are the miniaturization and affordability of satellites, the reduction of vulnerabilities and dependence on satellites (navigation, weapon guidance, etc.) and the development of (counter) space weapons.
3D printing & Materials	Using 3D printing, parts can be manufactured locally, which fundamentally changes maintenance concepts and logistics chains and produces new shapes. Developments in the field of materials technology concern new composites, nano- and metamaterials, which can be made in such a way that they are stronger or have more energy absorbing capacity than conventional materials, thereby reducing signatures.
Biotechnology	Technology for the application, breeding and adaptation of organisms. This includes traditional methods (for breeding, breeding, fermentation, etc.), modern methods based on genetic modification, and enabling methods such as bioinformatics. One of the most interesting new areas is synthetic biology: techniques for making very precise modifications to existing organisms or even creating entirely new organisms.
Simulation & virtualisation	Technology aimed at developing and applying virtual environments with which and within which people and systems can interact. Development of methods, tools and resources in the following areas: (1) simulators, (2) standards/interoperability, (3) environment modelling, (4) behavior modelling, and (5) interaction modalities (speech, tactile, etc.). Current developments focus on merged reality (integrating real and virtual world) for planning, decision-making and training, and on the increasingly (near-) real-time ability to perform simulations so that they can directly feed the C2/decision-making process.
Human Performance & Training	Research aimed at improving physical, cognitive and/or mental performance. Development of methods, tools and resources in the following areas: (1) selection, (2) medical care, (3) education and training (O&T), (4) human-machine interfaces, and (5) human enhancement (by psychotropic drugs, nutrition, implants, neurotechnology or body-related systems/prosthetics). Examples of recent developments and innovations are: virtual training of medical skills, monitoring by means of wearables, deployment of artificial 'Intelligent tutors' for training, and development of lightweight external skeletons and exosuits.
Robotics & Autonomous systems	Vehicles that operate in the air, on the ground, on or under water and do not have a human operator on board. Development of methods, tools and resources in the following areas: (1) mechanical structure, (2) remote control, and (3) autonomous operation. Developments include increased autonomy, swarming, and increased endurance through lightweight and improved/other energy sources.
ICT & networks	It concerns technology in systems and networks for the electronic transmission or reception of information, both wired and wireless, and for the processing and storage of data. Research into methods, tools and resources in the following areas: (1) networks and data links, (2) information (processing) systems and services. Examples of developments are: adaptivity and self-configuration of networks, improved quality of real-time tactical data links, battlefield internet and big data solutions.
Behavioural engineering	Technologies and methods for (1) the analysis of social behaviour, based on data from social media, cameras, etc. (2) influencing behavior and (3) increasing resilience against influence. Developments include social engineering (as part of offensive cyber), AI technology for personalising or manipulating social media, use of trolls, and generation of dis- or misinformation and deepfakes (highly realistic manipulated images or video).

Technology Areas	Description
Energy	This concerns technologies for (1) energy storage (usually via batteries and fuel cells) and (2) energy conversion, such as technologies to use energy from the environment (fossil fuels, nuclear energy and renewable energy sources). Currently the most important developments are electrification and hybridization of vehicles/platforms, battery improvements (more economical, lighter, faster charging) and energy conversion and transition.

B SIPRI Military Expenditure

Country	**SIPRI Military Expenditure 2020**		
	Total spending in mln US dollars	**Per capita in US dollars**	**Share of GDP in %**
Asia			
China	252304	175	1,7
India	72887	52	2,9
Japan	49148	388	1,0
South Korea	45735	892	2,8
Pakistan	10376	47	4,0
Indonesia	9395	34	0,9
Taiwan	12154	510	1,9
Middle East			
Saudi Arabia	57519	1652	8,4
Israel	21704	2507	5,6
UAE	22755[37]	2469[38]	5,6[39]
Iran	15825	188	2,2
Egypt	4505	44	1,2
Africa			
South Africa	3150	53	1,1
Nigeria	2568	12	0,6
South America			
Brazil	19736	92	1,4
Colombia	9216	181	3,4
Argentina	2907	64	0,8
Venezuela	2127[40]	72[41]	2,3
Oceania			
Australia	27536	1079	2,1
Europe non-EU/NATO			
Russia	61712	422	4,3
Ukraine	5924	135	4,1
Reference			
Netherlands	12578	734	1,4

[37] Data from 2014, no data is available from recent years.
[38] Data from 2014, no data is available from recent years.
[39] Data from 2014, no data is available from recent years.
[40] Data from 2017, no data is available from recent years.
[41] Data from 2017, no data is available from recent years.

C SIPRI Arms Industry

Country	**SIPRI Arms Industry**[42]
Asia	
China	N/A[43]
India	Hindustan Aeronautics (38), Indian Ordnance Factories (56), Bharat Electronics (62)
Japan	Mitsubishi Heavy Industries (25), Kawasaki Heavy Industries (48), Fujitsu (72), IHI Corp. (82), Mitsubishi Electric. Corp. (97), NEC Corp. (99)
South Korea	Hanwha Aerospace (46), Korea Aerospace Industries (60), LIG NEX1 (67)
Pakistan	-
Indonesia	-
Taiwan	-
Middle East	
Saudi Arabia	-
Israel	Elbit Systems (28), Israel Aerospac4 Industries (39), Rafael (44)
UAE	-
Iran	-
Egypt	-
Africa	
South Africa	-
Nigeria	-
South America	
Brazil	-
Colombia	-
Argentina	-
Venezuela	-
Oceania	
Australia	Austal (80)
Europe non-EU/NATO	
Russia	Almaz-Antey (9), United Aircraft Corp. (15), United Shipbuilding Corp. (18), Tactical Missiles Corp. (26), United Engine Corp. (33), High Precision Systems (40), Russian Electronics (45), Russian Helicopters (52), KRET (53), UralVagonZavod (64)
Ukraine	UkrOboronProm (71)
Reference	
Netherlands	-

[42] This database presents the top-100 arms-producing and military services companies in the world excluding China. The database is lastly updated in 2018.
[43] China's military industrial base is not presented in this database. Although several Chinese arms-producing companies are large enough to rank among the SIPRI Top 100, it has not been possible to include them because of a lack of comparable and sufficiently accurate data.

D QS World Universities

The ratings that are used by QS World Universities are a combination of citations, academic reputation, number of international students and international cooperations. All data refer to the year 2021.

Country	**# in top-1000**	**QS World Universities**[44]
Asia		
China	51	Tsinghua University (15), Peking University (23), Fudan University (34)
India	21	Indian Institute of Technology Bombay (172), Indian Institute of Science (185), Indian Institute of Technology Delhi (193)
Japan	41	The University of Tokyo (24), Kyoto University (38), Tokyo Institute of Technology (56)
South Korea	29	Seoul National University (37), KAIST - Korea Advanced Institute of Science & Technology (39), Korea University (69)
Pakistan	7	National University of Sciences And Technology Islamabad (355), Pakistan Institute of Engineering and Applied Sciences (373), Quaid-i-Azam University (454)
Indonesia	8	Gadjah Mada University (254), Universitas Indonesia (305), Bandung Institute of Technology (313)
Taiwan	16	National Taiwan University (66), National Tsing Hua University (168), National Cheng Kung University (234)
Middle East		
Saudi Arabia	10	King Abdulaziz University (143), King Fahd University of Petroleum & Minerals (186), King Saud University (287)
Israel	7	The Hebrew University of Jerusalem (177), Tel Aviv University (230), Technion - Israel Institute of Technology (291)
UAE	8	Khalifa University (211), United Arab Emirates University (284), American University of Sharjah (348)
Iran	5	Sharif University of Technology (409), Amirkabir University of Technology (477), University of Tehran (591)
Egypt	4	The American University in Cairo (411), Cairo University (561), Ain Shams University (801)
Africa		
South Africa	7	University of Cape Town (220), University of Witwatersrand (403), University of Johannesburg (439)
Nigeria	0	-
South America		
Brazil	14	Universidade de São Paulo (115), Universidade Estadual de Campinas (233), Universidade Federal do Rio de Janeiro (380)
Colombia	11	Universidad de los Andes (227), Universidad Nacional de Colombia (259), Pontificia Universidad Javeriana (426)
Argentina	13	Universidad de Buenos Aires (66), Pontificia Universidad Católica Argentina (326), Universidad de Palermo (377)
Venezuela	4	Universidad Central de Venezuela (751), Universidad Católica Andres Bello (801), Universidad de Los Andes (801)

[44] Only the 3 highest ranked universities are listed; the ranking of each university is given in parentheses.

Country	# in top-1000	QS World Universities[44]
Oceania		
Australia	36	The Australian National University (31), The University of Sydney (40), The University of Melbourne (41)
Europe non-EU/NATO		
Russia	28	Lomonosov Moscow State University (74), Saint Petersburg State University (225), Novosibirsk State University (228)
Ukraine	6	V. N. Karazin Kharkiv National University (477), Taras Shevchenko National University of Kyiv (601), National Technical University "Kharkiv Polytechnic Institute" (651)
Reference		
Netherlands	13	Delft University of Technology (57), University of Amsterdam (61), Wageningen University & Research (115)

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