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# Study of the US DARPA Model and its Applicability to the Indian Defence Research and Development System

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# Chapter I
# Introduction

The **Defence Advanced Research Projects Agency** (**DARPA**) is an agency of the United States Department of Defence (DoD), responsible for the development of new technologies for use by the military. Ever since its inception, DARPA has been responsible for funding the development of many advanced technologies not only in the strategic and tactical military domains but also in fields that have had major technological impacts on the world as a whole. The ARPANET computer networking programme was a harbinger of the first hypertext system and an important precursor of the contemporary ubiquitous Graphical User Interface (GUI). The objective of the agency is to drive the technology superiority of the US military and prevent technology surprise from harming the nation's national security interests by sponsoring revolutionary, high-payoff research, thus, bridging the gap between fundamental discoveries and their military use.[1] To fulfill its assigned objective, the agency relies on diverse performers to apply multi-disciplinary approaches to both advance knowledge through basic research and create innovative technologies that address current practical problems through applied research. DARPA's scientific investigations span the gamut from lab efforts to the creation of full-scale technology demonstrations in the fields of biology, medicine, computer science, chemistry, physics, engineering, mathematics, material sciences, social sciences, neurosciences, and more.[2]

As the DoD's primary innovation engine, DARPA undertakes projects that are finite in duration but that create lasting revolutionary change. Its primary mission is to foster advanced technologies and systems that create fundamental "revolutionary" advantages for the US military. The agency does not perform research directly but rather conceives and finances projects, serving as an active broker among technology, military and, occasionally, policy communities. Consistent with its mission, DARPA pursues a portfolio of Research and Development (R&D) projects at

1. http://www.darpa.mil
2. http://www.darpa.mil/our_work/

different levels of risk and varying scales in a large variety of technology fields.

DARPA is independent from other more conventional military/Service R&D organisations and reports directly to the senior (DoD) management. It has a dedicated workforce of approximately 240 professionals directly managing a $2.8 billion budget.[3] These figures are "on-average" since DARPA focusses on short-term (two to four year) projects run by small, purpose-built teams. It receives from the US Congress a budget which it distributes, with oversight and policy direction from top DoD civilian officials.

Over the years, DARPA has worked to enhance the US national security by funding research and technology development that has not only improved military capabilities but also impacted people's lives as an offshoot of military technological advances. Since the very beginning, DARPA has been the space for innovative ideas that has led to ground-breaking discoveries.

Most importantly, the US political and defence communities recognise the need for a high-level DoD organisation to formulate and execute R&D projects that would expand the frontiers of technology beyond the specific requirements of the military Services and their laboratories.[4] In pursuit of this mission, DARPA has developed and successfully transferred technology programmes encompassing a wide range of scientific disciplines which address the full spectrum of national security needs.

## Aim

The aim of this paper is to study and analyse the US DARPA model and to draw out useful ideas and inferences for the Indian defence R&D system.

## Scope

The scope of the study is restricted to the study of DARPA of the USA (although such models exist with other countries as well) and drawing out a comparison with the Defence Research and Development Organisation (DRDO) and other defence R&D agencies in India. Data and material available in the open domain have been utilised to undertake this analysis.

3. http://en.wikipedia.org/wiki/DARPA
4. http://www.fas.org/irp/agency/dod/idarma.pdf

# Chapter 2
# Understanding the DARPA Model

## Historical Perspective[5]

DARPA was established in 1958 as the Advanced Research Projects Agency (ARPA) by US President Dwight D Eisenhower in response to the Soviet Union's Sputnik launch in 1957, which caught the US 'unawares and embarrassed', while the Soviets had developed the capacity to rapidly exploit military technology. ARPA's mission at that time was to ensure that US military technology was more sophisticated than that of the nation's potential adversaries. The vision set by the US Senate for ARPA at that time was,

> …this path breaking initiative is being undertaken for the purpose of forming and executing R&D projects to expand the frontiers of technology and science and be able to reach far beyond immediate military requirements….[6]

ARPA was renamed as "DARPA" in March 1972, then renamed "ARPA" in February 1993, and, finally, redesignated as "DARPA" again in March 1996.

From 1958 to 1965, ARPA's emphasis centred on major national issues, including space, ballistic missile defence and nuclear test detection. During 1960, all of its civil space programmes were transferred to the National Aeronautics and Space Administration (NASA) and the military space programmes to the individual Services. This allowed ARPA to concentrate its efforts on the Project DEFENDER (defence against ballistic missiles), Project Vela (nuclear test detection) and Project AGILE (counter-insurgency R&D) programmes and to begin work on computer processing, behavioural sciences and material sciences. The DEFENDER and AGILE programmes formed the foundation of DARPA's sensor, surveillance and directed energy R&D, particularly in the study of radar, infrared sensing, and X-ray/gamma ray detection. ARPA also played an early role in Transit (also called NavSat)

5. http://en.wikipedia.org/wiki/DARPA
6. Extract of speech by Secretary of State (Def) in the House of Representatives.

a predecessor of the Global Positioning System (GPS). In 1959, a joint effort between DARPA and the John Hopkins Applied Physics Laboratory began to fine tune the Project Transit, sponsored by the US Navy, giving the world its first satellite positioning system.

During the late 1960s, with the transfer of mature programmes to the Services, ARPA redefined its role and concentrated on a diverse set of relatively small, essentially exploratory research programmes. During the early 1970s, it emphasised on direct energy programmes, information processing and tactical technologies. DARPA supported the evolution of the ARPANET (the first wide-area packet switching network), Packet Radio Network, Packet Satellite Network and, ultimately, the Internet and research in the fields of Artificial Intelligence (AI), speech recognition and signal processing. DARPA also funded the development of the Douglas Engelbart's NLS computer system and 'Mother of All Demos' and 'Aspen Movie Map', which was probably the first hypermedia system and an important precursor of virtual reality.

The Mansfield Amendments of 1973 expressly limited appropriations for defence research through ARPA/DARPA, to projects with direct military applications. From 1976 to 1981, DARPA's major thrust areas were dominated by air, land, sea and space technologies, tactical armour and anti-armour programmes, infrared sensing for space-based surveillance, high-energy laser technology for space-based missile defence, anti-submarine warfare, advanced cruise missiles, advanced aircraft and defence applications for advanced computing.

Many of the successful programmes were transitioned to the Services, such as the foundation technologies in automatic target recognition, space-based sensing, propulsion and materials. These programmes were transferred to the Strategic Defence Initiative Organisation (SDIO), later known as the Ballistic Missile Defence Organisation (BMDO) and now titled the Missile Defence Agency (MDA).[7]

During the 1980s, the attention of the agency was centred on information processing and aircraft related programmes, including the National Aerospace Plane (NASP) or Hypersonic Research Programme. The Strategic Computing Programme enabled DARPA to exploit advanced processing and networking

7. http://en.wikipedia.org/wiki/DARPA

technology and to rebuild and strengthen relationships with universities after the Vietnam War. In addition, DARPA began to pursue new concepts for small, lightweight satellites (LIGHTSAT) and directed new programmes regarding defence manufacturing, submarine technology and armour/ anti-armour.

## The Changing Face of DARPA

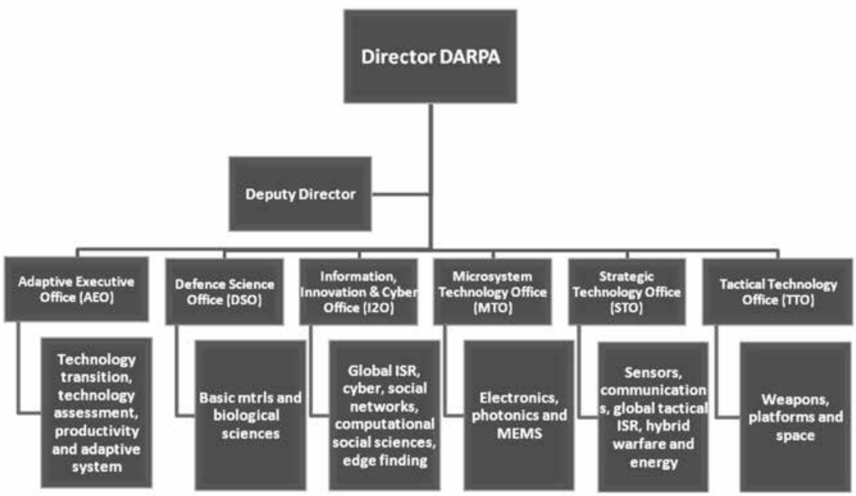
During the 1960s, on inception, DARPA focussed on fundamental research. Its environment was characterised by scientific merit over military competence, complete independence, high quality of intellect and hiring of the best people in the business. During the 1970s, a shift of focus occurred towards military missions and an element of periodic reviews and definable measures of success of programmes was introduced. Thereafter, the 1980s saw an era of industrial competitiveness, possibly spurred by the shift to military missions in the earlier decade. The environment was now characterised by formation of certain technology groups aimed at connecting the academia and industry. During the 1990s, the focus was on making DARPA competitive with the US defence R&D industry and internationalisation of its resource base. Priority was, therefore, accorded to human resource development, outreach and experimentation. In the current decade, a distinct shift from industry to military applications has been perceptible. The DARPA of today aims to bridge the gap between research and military applications, works on distinct well defined milestones and phases, and enforces a high degree of accountability.

## Highlights of the DARPA Model

### Organisation

DARPA maintains a small, flat and agile organisation. When DARPA was created, it reported to the Secretary of Defence and was assigned projects by the White House. Today, the Director, DARPA reports to the Director of Defence Research and Engineering (DDR&E), who reports to the Under Secretary of Defence for Acquisition, Technology and Logistics, who, in turn, reports to the Secretary of Defence. Under the Director, DARPA is a Deputy Director, Directors and Deputy Directors for its half dozen or so standing offices and individual Project Managers (PMs). It is organised into six project offices, all of which directly report to the Director, DARPA. The outline organisation of DARPA and thrust areas of the respective programme offices is as under[8]:

**Fig I: Outline Organisation of DARPA**




An analysis of the broad charter reflects a deep involvement of the various programme offices with the US defence forces which brings forth the synergy among the researcher, the developer and the user. The major charters of these project offices[9], are as under:

8. http://www.darpa.mil/our_work/
9. http://www.DARPA/Organization.htm

- **AEO:** The AEO prepares and coordinates field trials of advanced technologies developed by DARPA. At any point in time, DARPA has technology in all stages of development, from nascent ideas to systems ready for fielding. Working with Combatant Commands (COCOMs) and Service partners, AEO establishes relationships that enable the rapid insertion of these technologies into military operations and exercises to address requirements and enhance war-fighting capabilities. In the process, DARPA Project Managers (PMs) receive direct feedback on the operational utility of the prototype technology, have access to real world data and achieve an increased understanding of how technology performs in field conditions. The COCOMs and Services, on their part, get early exposure to DARPA technology and better understanding on how emerging capabilities develop into an operational system. The direct feedback and performance data from these interactions improves individual DARPA programme development, execution and DARPA's strategic planning and direction. The agency has a unique perspective on emerging technologies, trends and potential opportunities to synthesise advances in disciplines that may be brought to bear quickly to serve the war-fighter. AEO's programme for DARPA-COCOM interaction is the DARPA Forward Cell (DFC), a full-time forward presence in the combat zone.
    - **DSO:** The DSO vigorously pursues the most promising technologies within a broad spectrum of the science and engineering research communities and developing these technologies into important, radically new military capabilities. DSO programmes bridge the gap between fundamental science and military applications by identifying and pursuing the most promising ideas and transforming these ideas into new DoD capabilities.
    - **I2O:** I2O aims to ensure US technological superiority in all areas where information can provide a decisive military advantage. It explores game-changing technologies in the fields of information science and software to anticipate and create rapid shifts in the complex national security landscape. I2O's research portfolio is focussed on anticipating new modes of warfare in these emerging areas and developing the concepts and tools necessary to provide decisive advantage for the

US and its allies. The I2O defence cyber portfolio is largely focussed on changing this paradigm through a variety of methods such as heterogeneity, formal method proofs, secure code generation and automation. The I2O portfolio covers a broad space, investigating enterprise networks, secure communications, industrial systems and purpose-built military systems.

- **MTO:** The MTO supports DARPA's mission of creating and preventing strategic surprise by investing in areas such as Micro-Electro Mechanical Systems (MEMS), electronics, computing, photonics and biotechnology. In recent years, the proliferation of commercial components and manufacturing processes has made advanced technologies accessible to all, levelling the playing field. In response, the MTO is dedicated to leveraging, countering and transcending these Commercial-Off-The-Shelf (COTS) approaches. The MTO aims to multiply the power of COTS by aggregating, adapting and integrating components into networks and systems for the benefit of the war-fighter. The MTO seeks methods for countering threats (both incidental and intentional) that arise from sustained advancements in cheap and readily available technologies. Lastly, the MTO develops high-risk, high-reward technologies outside and beyond the scope of the commercial industry to secure the DoD's technological superiority. By continuing to create revolutionary capabilities, the MTO seeks to "un-level" the playing field.
- **STO:** The STO is focussed on technologies that enable fighting as a network to increase military effectiveness, cost leverage and adaptability. The STO's areas of interest including Battlefield Management Command and Control (BMC2), Communications and Networks (C&N), Intelligence, Surveillance and Reconnaissance (ISR), Electronic Warfare (EW), Positioning, Navigation and Timing (PNT) and foundational strategic technologies and systems. The STO's mission is to focus on technology that has a global theatrewide impact and which involves multiple Services.
- **TTO:** The TTO engages in high-risk, high-payoff advanced military research, emphasising the "system" and "sub-system" approach to the development of aeronautic, space and land systems as well as

embedded processors and control systems. It develops new prototype military capabilities that create an asymmetric technological advantage and provide US forces with decisive superiority and the ability to overwhelm its adversaries. The TTO's objective is to provide or prevent strategic and tactical surprise with very high-payoffs, high-risk development of revolutionary new platforms, weapons, critical technologies and systems.

## DARPA's Strategy and Framework[10]

DARPA's investment strategy begins with a portfolio approach. Taking on risk and high-risk in pursuit of high-payoffs is a hallmark of DARPA's programmes. DARPA's culture encourages taking risks and tolerates failure. By design, programmes are finite while creating lasting revolutionary changes. These programmes address a wide range of technological opportunities and national security challenges. This assures that while individual efforts might fail, the total portfolio delivers. DARPA PMs define and propose new programmes they believe promise revolutionary change. An effective DARPA PM is the person closest to the critical challenges and possible technological opportunities in his or her arena. DARPA focusses on three essential, interdependent strategic objectives to carry out its mission:

- Demonstrate breakthrough capabilities for national security.
- Catalyse a differentiated and highly capable US technology base.
- Ensure DARPA itself remains robust and vibrant to deliver on its mission today and in the future.

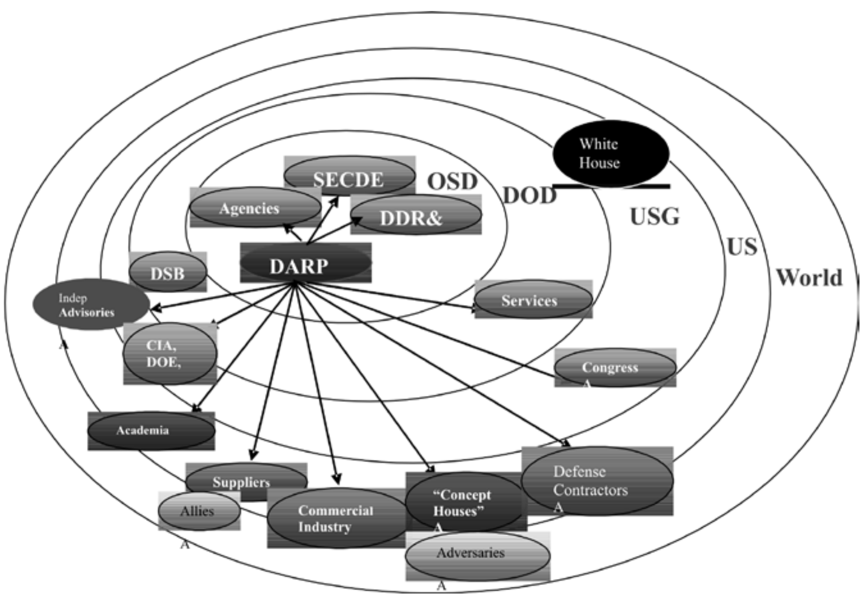
DARPA interacts with a plethora of agencies to foster a novel relationship based on a win-win situation for all stakeholders. It organises several national level technology competitions and seminars for promoting innovations and ideas. It has its feeds on all the major technology related websites, some of which are as listed under:

- Fed Scoop hosts a dashboard for DARPA news.
- DARPA's past and current project list is available at http://www.technovelgy.com.

10. DARPA Framework 2013 – Driving Technological Surprise: DARPA's Mission in a Changing World.

- The DARPA homepage offers images and general information about the programmes.
- DARPA regularly solicits proposals for partnerships and original research through its website.
- 'Popular Science' follows DARPA developments closely and regularly posts news about its innovations.
- DARPA runs a You Tube channel offering videos of testing, news conferences and more.
- The DARPA Grand Challenge is an annual robotics competition.
- The organisation is heavily involved in social media, including a very active Twitter account.
- A timeline of DARPA's innovations is also available on its website.

**Fig 2: DARPA's Linkages with Outside Organisations/Agencies**




## Funding Mechanism

To help DARPA attract top technological talent outside the government and to encourage a steady stream through the agency of new PMs with fresh ideas, it has been granted flexible hiring authority that allows it to offer limited term appointments. The primary recipients of DARPA funds are researchers and research organisations in industry and universities, with smaller amounts going to US government and federally funded laboratories[11]. Start-up firms have frequently played a lead role, more so, if a technology has substantial commercial potential or when DARPA ideas could impact the long-term competitive position of existing firms' products. As suggested in Fig 2, DARPA acts as a catalyst for innovation by seeding research communities in promising new technology areas, making iterative investments in the underlying technological base from development through proof-of-concept. In some cases, DARPA funds large scale demonstrations that integrate individual components. Performing a demonstration may require DARPA to act as a "system of systems" integrator, funding the engineering work required to meld different system functions into a new capability that is more than the sum of its parts.

## Salient Features of the DAPRA Model

DARPA represents less than one percent of the US R&D spending and four percent of the DoD budget for Research, Development, Testing and Evaluation (RDT&E)[12]. Its unique model is one that engages with companies, universities, DoD and scientific laboratories. Salient features of DARPA are as under:

- **Small and Flexible Organisation:** DARPA has only about 140 technical professionals – some have referred to DARPA as "100 geniuses connected by a travel agent".
- **Flat Organisation:** DARPA avoids hierarchy, essentially operating at only two management levels to ensure the free and rapid flow of information and ideas and rapid decision-making.
- **Autonomy and Freedom from Bureaucratic Impediments:** DARPA provides for a direct hiring authority to hire talent with the expediency not allowed by the standard civil service process.
- **Eclectic, World-Class Technical Staff and Performers:** DARPA seeks great talent ideas from industry, universities, government

11. http://www.fas.org/irp/agency/dod/idarma.pdf
12. n.10.

laboratories and individuals, mixing disciplines and theoretical and experimental strengths. DARPA neither owns nor operates any laboratories or facilities and the overwhelming majority of the research it sponsors is done in industry and universities. Very little of DARPA's research is performed at government laboratories.

- **Teams and Networks:** At its very best, DARPA creates and sustains great teams of researchers from different disciplines that collaborate and share in the team's advances.
- **Hiring Continuity and Change:** DARPA's technical staff is hired or assigned for four to six years. Like any strong organisation, DARPA mixes experience and change. It remains a base of experienced experts – its office Directors and support staff are knowledgeable about DoD and its procedures. The staff is rotated to ensure fresh thinking and perspectives and to have room to bring technical staff from new areas into DARPA.
- **Project-based Assignments Organised Around a Challenge Model:** DARPA organises a significant part of its portfolio around specific technological challenges. It foresees new innovation-based capabilities and then works back to the fundamental breakthroughs required to make them possible. Although individual projects typically last three to five years, major technological challenges may be addressed over longer time periods, ensuring patient investment on a series of focussed steps and keeping teams together for ongoing collaboration. Continued funding of DARPA projects is based on passing specific milestones, sometimes called "go's/no-go's".
- **Outsourced Support Personnel:** DARPA extensively leverages technology, contracting and administrative services from other DoD agencies and branches of the military. This provides DARPA the flexibility to get into and out of an area without the burden of sustaining staff, while building cooperative alliances with its "agents". These outside agents help create a constituency in their respective organisations for adopting the technology.
- **Outstanding Programme Managers (PMs)**: The best DARPA PMs have always been freewheeling zealots in pursuit of their goals. The Director's most important task is to recruit and hire very creative people with big ideas and empower them.

- **Acceptance of Failure:** DARPA pursues breakthrough opportunities and is very tolerant of technological failure, if the payoff from success is expected to be great enough. PMs are encouraged to challenge the traditional thinking and approaches to national security problems and to be outcome oriented.
- **Orientation to Revolutionary Breakthroughs in a Connected Approach:** DARPA historically has focussed not on incremental but radical innovation. It emphasises high-risk investment, moves from fundamental technological advances to prototyping and then hands over the system development and production to the military Services or the commercial sector.
- **Mix of Connected Collaborators:** DARPA typically builds strong teams and networks of collaborators, bringing in a range of technology expertise and applicable discipline, and involving university researchers and technology firms that are often not significant defence contractors.

## Game-Changing New System Technologies[13]

DARPA has a long history of developing and demonstrating new system capabilities that change what is possible. A list of current projects being handled by DARPA is given at Appendix A. Today's war-fighters rely on systems ranging from aircraft to navigation to communications that trace their roots to earlier DARPA work. Looking ahead, these key capabilities may become vulnerabilities, as sophisticated adversaries also understand how critical they are to the US' ability to fight. DARPA, therefore, seeks to create the next generation of new capabilities that once again change the equation in favour of the US, faster than others can respond. Game changers being worked upon by DARPA are as under:

- **Layered, Multi-Technology War-Fighting Concepts**
  Combining multiple technological advances by layering and integrating them can lead to a revolution in capabilities. Looking ahead, we can imagine coordinating local Position, Navigation and Timing (PNT), adaptive Electronic Warfare (EW), manned and unmanned systems working in harmony, tactical cyber effects and advanced Intelligence, Surveillance and Reconnaissance (ISR) – all woven together in ways that create decisive surprise.

13. Ibid.

- **Adaptable Systems and Solutions:** When we consider future engagements, we can more readily imagine a host of diverse environments and adversaries. In an uncertain world, adaptability is critical. We won't always know exactly what we will need for tomorrow's battle and our adversaries too will change their tactics and technologies over time. Systems that can be readily upgraded and can adapt in real time to changing surroundings and conditions will, therefore, stand to play an important role.
- **Innovation to Invert the Cost Equation:** Cost control and affordability constraints are usually addressed during the requirement analysis and development phase of programmes, but these concepts need to be considered earlier. DARPA seeks to use innovation to radically invert the cost dynamics. It works on how we can impose more cost on our adversaries and less of it on ourselves, thereby increasing our deterrence capability. It also explores if we can employ innovative systems, architectures, autonomy, adaptability and new processes to offer new possibilities. These approaches may allow us to reinvent development, production, logistics, operations and maintenance in ways that radically change the cost equation.

## Current Thrust Areas of DARPA[14]

- **Networks:** Self-forming, robust, self-defending networks at the strategic and tactical levels are the key to network-centric warfare.
- **Chip-Scale Atomic Clock:** Miniaturising an atomic clock to fit on a chip to provide very accurate time as required, for example, in assured network communications.
- **Global War on Terrorism:** Technologies to identify and defeat terrorist activities such as the manufacture and development of Improvised Explosive Devices (IEDs) and other asymmetric activities.
- **Aerial Vehicles:** Manned and Unmanned Aerial Vehicles (UAVs) that quickly arrive at their mission station and can loiter there for very long periods of time.
- **Space:** The US military's ability to use space is one of its major strategic advantages and DARPA is working to ensure the United States maintains the military advantage in the field of space.

14. http://en.wikipedia.org/wiki/DARPA

- **High Productivity Computing Systems:** Supercomputers are fundamental to a variety of military operations from weather forecasting to cryptography to the design of new weapons. DARPA is working to maintain the global lead in this technology.
- **Real-Time Accurate Language Translation:** Real-time machine language, translation of structured and unstructured text and speech with near-expert human translation accuracy.
- **Biological Warfare Defence:** Technologies to dramatically accelerate the development and production of vaccines and other medical therapeutics from 12 years to only 12 weeks.
- **Prosthetics:** Developing prosthetics that can be controlled and perceived by the brain, just as with a natural limb.
- **Quantum Information Science:** Exploiting quantum phenomena in the fields of computing, cryptography and communications.
- **Low-Cost Titanium:** A completely revolutionary technology for extracting titanium from the ore and fabricating it promises to dramatically reduce the cost of military-grade titanium alloy, making it practical for many more applications.
- **Alternative Energy:** Technology to help reduce the military's reliance on conventional energy sources, viz, petroleum products, etc.
- **High Energy Liquid Laser Area Defence System:** Novel, compact, high power making practical, small-size and low-weight, speed-of-light weapons for tactically mobile, air and ground vehicles.

# Chapter 3
# The Indian Defence R&D Scenario

Prior to analysing the Indian defence R&D scenario, it is imperative to define R&D and briefly discuss the overall national approach to R&D. R&D may be defined as the process of discovering new knowledge about products and services, and application of such knowledge to create new and improved products/processes to meet market requirements. The phrase research and development, according to the Organisation for Economic Cooperation and Development (OECD), refers to "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications". R&D involves constant revitalisation of knowledge and expertise, and could result in developments such as:

- New/improved products.
- Improved operational processes.
- Meeting the changing requirements of customers.
- Cost reduction.
- Meeting the changing social and environmental needs.

R&D is generally undertaken by the industry, academia as well as the government. Although businesses have traditionally developed research capabilities in-house, they have also established collaborative links with other organisations such as universities, and acquired technology from other enterprises through licensing or takeovers. R&D in specific areas can yield significant benefits to the nation as a whole, however, it may not be cost effective for investment by the private sector. Hence, there is a necessity for the government to step in and support R&D efforts. The rationale for government's participation in R&D may include the following:

- Innovations resulting in cost reduction across all consumers: R&D is in the interest of the society, but it may not be pursued by the industry since there are no direct benefits to the industry.

- Innovations enhancing the value of assets not reflected in the financials of the industry, for instance, national defence.
- Innovations impacting environmental and other externalities may not be pursued by the industry unless regulations, emission charges or other policies mandate such requirements, viz, innovations for eco-friendly products/ processes, use of non-conventional energy, etc.
- Research that is costly and has a high chance of failure may exceed the risk threshold of the private sector, even though, from a societal point of view, having a certain number of such projects in the national R&D portfolio is worthwhile because occasional successes can bring very high gains.
- Research that has a long gestation period is likely to fall short of the private sector's requirement for a rate of return attractive to investors, even if confidence in achieving success is high.

## R&D Spending

The pace of technological progress is directly proportional to the efforts on R&D. The expenditure levels on R&D could, therefore, act as reliable indicators of innovative capacity. In terms of spending, the United States is the largest of the global spenders on R&D, followed by Japan and China. The major spenders within Europe are Germany, France, and the UK. The industries that lead in worldwide total R&D spending are automobiles, health care, computing, electronics and defence.

**Table 1: Global R&D Spending[15]**

| Global R&D Spending (in Billion US$) | 2012 GERD PPP* (in Billion US$) | 2012 R&D as % of GDP | Share of Total Global R&D Spending |
|---|---|---|---|
| Americas | 505.6 | 2.3% | 36% |
| USA | 436 | 2.8% | 31.1% |
| Asia | 514.4 | 1.9% | 36.7% |
| Japan | 157.6 | 3.5% | 11.2% |
| China | 198.9 | 1.6% | 14.2% |
| **India** | **41.3** | **0.8%** | **2.9%** |

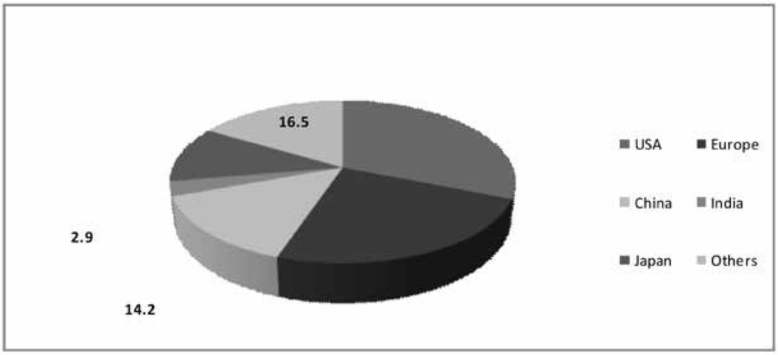
15. Source: *Battelle*, R&D Magazine(http://www.rdmag.com/articles/2011/12/2012-global-r-d-funding-forecast-r-d-spending-growth-continues-while-globalization-accelerates)

| | | | |
|---|---|---|---|
| Europe | 338.1 | 2.0% | 24.1% |
| Rest of the World | 44.5 | 1.1% | 3.2% |
| | 1402.6 | | |

*PPP – Purchasing Power Parity
GERD – Gross Domestic Expenditure on R&D

The chart below brings out a comparison of spending by countries such as China and India, with the countries that lead innovation.

**Chart 1: Comparison of Spending by Countries on R&D[16]**

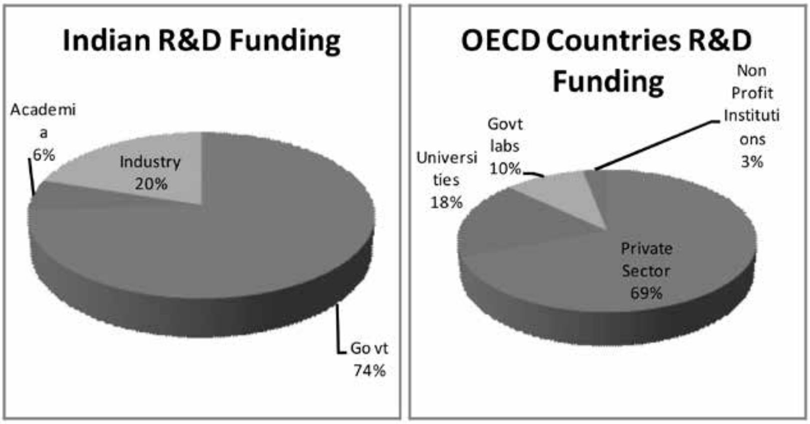



An analysis of the above data presents the abysmal interest and priority that India gives to R&D, despite being one of the largest producers of intellectuals, in terms of the number of doctorates and post-graduates that qualify each year from the numerous universities nationwide**.** World data on R&D spending is given at Appendix B.

It is interesting to understand the R&D funding pattern in various countries. The private sector finances nearly 70 percent of total R&D spending in the United States and approximately 75 percent of total R&D spending in Korea and Japan. While in India, a notable 80 percent of total R&D expenditure is funded by the government, 18 percent by private enterprises and only 2 percent by universities. On the contrary, the typical R&D expenditure break-up in OECD countries is 69 percent by private enterprises, 18 percent by universities, 10 percent by R&D labs and 3 percent by non-profit institutions.[17] A comparison of the funding pattern in India and OECD countries is reflected in the pie chart below:

16. *Battelle,* R&D Magazine – 2012 RD Funding Report.
17. R&D Expenditure – A Concept Paper, July 2011, Deloitte.

**Chart 2: Comparative Funding on R&D**[18]




## In-House Development

In-house development of technology through R&D is an exercise fraught with a high degree of risk in an environment of uncertainty. As a starter, there must be acceptance of the truth that some failures are inevitable and these are far in excess of successful outcomes. However, notwithstanding these aspects, investment in R&D has long-term benefits. Strategic planners must be acutely aware of this, thus, leading to a sound R&D policy. To be effective, R&D thrust must flow out of an organisational strategy. Such integration permits appropriate resource allocation in the following areas:

- Basic (or fundamental) research.
- Development of existing technologies.
- Adaptation of transferred technologies.
- Indigenisation/substitute development.
- Integration of multi-source technology, leading to development of composite technology.

Ironically, all stakeholders in defence R&D in India, including R&D organisations, the Services as well as the bureaucracy (decision-makers) do not follow the above globally acceptable approach to defence research.

18. Ibid.

## Public Sector R&D

Indigenous R&D spending in general and on defence in particular as a share of Gross Domestic Product (GDP) remains low and is dominated by the public sector. The public sector accounts for 70-80 percent of India's total R&D investment, equal to approximately 0.8 percent of the GDP[19]. The bulk of the effort is mission oriented R&D in defence, space and energy. Public R&D is executed by the creation of various support programmes and project execution through a network of laboratories, establishments and field stations. Although these programmes have achieved significant success, their effectiveness has not matched the needs of the Indian economy or been commensurate with the resources invested in them. This imbalance is not only a loss for specific programmes but more importantly, represents many missed opportunities for the nation. Private sector involvement has been minimal since most programmes have been operated and managed by government institutions. Public sector institutions typically suffer from complex, overlapping structures for policy and decision-making. This public sector approach reflects a preference for government ownership and management of the initiatives, rather than leveraging private sector capacities to provide investments, modern management, risk taking and needed skills, designs and operational flexibility. The rigid bureaucratic resource allocation procedures, combined with the lack of risk taking and clear accountability in many public sector institutions, may be the main reasons for the limited effectiveness of the government R&D programmes[20]. The Indian public sector defence R&D is primarily undertaken by the DRDO with minuscule efforts by the Defence Public Sector Undertakings/ Ordnance Factories (DPSUs/OFs) on their own.

## An Assessment of the Public Sector R&D System

An assessment of the public R&D system reveals that relative to India's economic size and the international context, the quantum of public research is fairly low. The effectiveness of public R&D spending is also low as is evident from the limited commercialisation of technology generated by the public sector R&D system[21]. Some of the major misgivings of the system are as under:

19. A Brief Report on Defence Sector in India, August 2012 , ASA & Associates.
20. http://www.indianbusiness.nic.in/newdesign/index.php?param=industries_landing/357/2
21. Defence R&D, What India Needs To Do, www.rediff.com/news/12-defence-rand-what_india_needs_to_do.htm

- There are no national governance structures for innovation leading to overlapping and loss of system effectiveness.
- **Processes are slow, bureaucratic and hierarchical**. An innovation system needs to function and perform much faster and be responsive.
- **With few exceptions, the focus is on getting more funds for each programme**. More attention needs to be paid to monitoring and evaluation of effectiveness and systematic international benchmarking of programmes.
- **There is a narrow definition of innovation**. R&D is given more emphasis over innovation. R&D may be the easiest and most visible indicator for pursuing innovation, but it does not constitute innovation.
- Although the goals of research institutes in different areas and the conduct of different functions (basic versus applied research) will differ in how they are organised and against what criteria they are evaluated, in general, there is no clear orientation towards results or accountability. Most public research laboratories do not have clearly monitorable objectives.
- **Interaction**. Public research institutes should not work in isolation from other public research institutes, universities and the production/manufacturing sector. Global experience shows that greater interaction among these three main research performers improves the quality and relevance of research.
- The public R&D system as a whole would benefit from an independent evaluation and restructuring to take greater advantage of cross-institution synergies and increase their focus on commercialisation. Budgetary allocations to poorly performing institutions and programmes may be gradually reduced, making them more competitive. Accordingly, more public funding should be offered competitively to programmes and institutions that meet specified criteria and win the funds in peer-review competitions.

# Chapter 4
# DRDO – The Failings So Far

The public sector defence R&D in India has been primarily driven by DRDO. In 2011, the Comptroller and Auditor General (CAG) put a serious question mark on DRDO's capabilities, "…the organisation, which has a history of its projects suffering endemic time and cost overruns, needs to sanction projects and decide on a probable date of completion on the basis of a conservative assessment of technology available and a realistic costing system…", its report stated.[22] The CAG also observed that nearly 60 percent of the products that DRDO produced were rejected by the armed forces, while crucial projects were delayed for decades. Some of the more notable delays of DRDO projects are:

- **The Arjun Main Battle Tank** has taken over 40 years for development and the end product is nearly 50 percent overweight, which prevents it from being deployed in all terrains by the Indian Army. The heart of the tank, the fire control system was supposed to be jointly developed by DRDO and Israel but is presently being procured from Elbit Systems, Israel.
- **The Light Combat Aircraft (LCA) Tejas**, the lightweight multi-role combat aircraft, which has been in the making for 30 years, has gone through several phases of streamlining on the drawing board after the Indian Air Force (IAF) expressed reservations about its faulty initial design. The LCA which is supposed to replace India's ageing fleet of MiGs, is still in the flight test stage and yet to be accorded the final operational clearance. Only the control system and airframe are indigenous. All other components, including the ejection seat, are imported.
- **The Nag anti-tank missile**, the project for the third generation missile system, has been delayed by over 30 years. The missile recently cleared land-to-land preliminary trials in September 2013 but is yet to clear the previously failed air-to-ground trials of October 2011.

22. http://indiatoday.intoday.in/story/drdo-failed-in-its-mission-due-to-delay-high-cost/1/184335.html

- **The Trishul anti-aircraft missile** project was finally foreclosed in 2008 after 20 years of research, design and development costing over several hundred crores of rupees.
- **The Kaveri engine for the LCA** had a 16-year delay, with cost escalation of over 800 percent. The engine is still not airworthy. Delays in the engine have compounded delays in the LCA programme.
- Even the most basic defence items such as artillery guns and howitzers have not been developed by DRDO so far.
- The success stories of DRDO, the **Agni and Prithvi range of missiles**, have, of late, failed a series of user trials. Their low reliability (50 percent probability of successful strike coupled with hours of pre-launch preparations) causes the very credibility of our nuclear deterrence to be questioned.[23]
- The premier **Nishant UAV** developed by DRDO is not aerodynamic and takes hours to deploy and launch.

## Comparative Analysis of DARPA and DRDO

A comparative analysis of DARPA and DRDO throws up startling facts, as listed under[24]:

- Both organisations were established in 1958.
- The DRDO annual budget is Rs 10,253.17 crore (US $ 1.8 billion) as compared to DARPA, which has a budget of US $ 2.8 billion.
- DRDO has a workforce of approximately 7,000 scientists and 25,000 technical staff and support personnel as compared to DARPA which has only 240-odd personnel, including 140 technical staff.
- DRDO has a dedicated state-of-the-art laboratory infrastructure comprising a network of 52 laboratories as compared to DARPA which operates from academia, corporate and government laboratories.
- DARPA has field stations (DARPA Forward Cells in Combat Commands) in Afghanistan and Iraq, where they field emerging technologies and get direct feedback from forward troops and Combat Commands on the military application of these. This also instills user confidence in equipment delivered by DARPA apart from being involved in future technologies.

23. www.ibtl.in/news/opinion/2029/**drdo**-indias-lumbering-dinosaur
24. http://en.wikepedia.org/wiki/Defence_Research_and_Development_Organisation

- DARPA participates actively in the conduct of field trials.
- The Director, DARPA reports to the Secretary of Defence and DoD through the Director of Defence Research and Engineering and Under Secretary Defence for Acquisition, while the Director General (DG), DRDO is directly under, and is nominated as Scientific Advisor to, the Raksha Mantri (RM). The DRDO command and control model is, therefore, devoid of the Services' inputs to an organisation which is responsible for defence R&D.
- While DARPA and DRDO were established around the same time, DARPA has moved far ahead and established global benchmarks in defence R&D while DRDO is burdened with increased bureaucracy, endemic cost and time overruns, high expenditure on defence R&D, low risk taking appetite and virtually no accountability to the Services.
- DARPA projects typically last three to five years while some DRDO projects are spanning over two to three decades and finally lead to foreclosure.

# Chapter 5
# Private Sector R&D

The world has acknowledged India's R&D potential. More than 300 Multinational Corporations (MNCs) have set up R&D and technology centres in India. Despite the recent increase in R&D spending, public sector R&D agencies and other domestic enterprises have not systematically exploited this potential to India's advantage. Indigenous enterprise R&D and innovation are on the rise and above the Indian average in the pharmaceutical, automotive, Information Technology (IT) and software sectors. The private sector has increasingly recognised the need for further innovation. The key challenges faced by companies include measuring returns on innovations, moving quickly from idea generation to commercialisation and launch, and balancing risks, timeframes and returns across a portfolio of new projects. These findings imply that better monitoring and management training and tools for innovation are becoming increasingly important for Indian firms. MNCs have discovered that India is an excellent location for R&D. In several international surveys, investors have ranked India as their preferred destination for locating innovation centres (69 percent of firms consider India their preferred site – compared with 8 percent for China).[25]

Global firms are using three strategies to source innovations in India[26]:

- Locating innovation centres in India through fully owned local subsidiaries.
- Outsourcing innovations to Indian research centres and firms.
- Acquiring innovative entrepreneurial firms and start-ups.

## R&D Links Between MNCs and Academia

Consultancy by the academic community has been the most direct and preferable route to industry-academic interactions in more than 1,000 R&D institutions and research laboratories. Major financial institutions such as the Industrial Development Bank of India (IDBI), Industrial Finance Corporation of India (IFCI) and Industrial Credit and Investment Corporation of India

25. n.17.
26. http://www.indianbusiness.nic.in/newdesign/index.php?param=industries_landing/357/2

(ICICI) have also promoted the use of consultants by establishing state-level consultancy organisations. Traditionally, Memorandums of Understanding (MOUs) have been the only formal path to establish working relationships between the industry and academic institutions. Formal licensing arrangements have not been a practice in most MOUs, as the ownership of any Intellectual Property (IP) was unilaterally given to the funding agency. In most cases, the knowledge generated or improvements made in technology in such consultancy projects have become a part of the knowhow portfolio of the industries sponsoring the projects. Concepts of valuation of the knowledge generated, its commercial impact, etc were not necessarily the criteria to arrive at the remuneration for sponsored projects by industries. The concept of a holistic management of Intellectual Property Rights (IPR) as an integral part of project management is an emerging area that will need a few years to mature. Such an approach to interactive working has, therefore, not resulted in proactive research planning on the part of the academic institutions but has been short-term, narrow, problem-based; therefore, patchy technology development has not led to a major technology and IPR portfolio of the academic institutions or the industries.

The concept of institutional IPR policies in academic institutions in India is in its infancy, with only a handful of institutions such as the Council of Scientific and Industrial Research (CSIR), Indian Institute of Technology (IIT), Bombay, IIT, Kharagpur, IIT, Delhi, and Pune University formally announcing their IPR policies and guidelines for interactions with other institutions, industries, etc. The role of industry organisations such as the Confederation of Indian Industries (CII), Federation of Indian Chambers of Commerce and Industry (FICCI), etc., has also been peripheral and restricted to organisation of conferences / workshops, with short-term objectives and, therefore, not yet resulted in establishing a framework for facilitating and canalising or even providing a conduit for academic-industry interaction.

Notwithstanding, the huge influx of Foreign Direct Investment (FDI) in India's electronics and IT sectors has led to a growing number of university-industry partnerships. Institutes of Science (IISc) and other specialty institutes are hubs for innovation fuelled by investments from overseas IT companies.

# Chapter 6
# Indian Defence R&D Reforms

DARPA was set up by the US government in 1958, the same year that DRDO was born in India. DRDO has, ever since, rapidly grown in terms of strength and funding. While DARPA has a scientist to support staff ratio of 1.4:1, the corresponding figure for DRDO is 1:5. Although the US defence budget is almost 25 to 30 times larger than that of India, DARPA's annual budget is only twice the size of DRDO's.[27] The qualitative difference in the output of DARPA and DRDO is too well-known. After the Group of Ministers (GoM) in their post-Kargil review had raised several questions about the efficacy of DRDO, other committees have followed suit. The two most notable among them which have made concrete recommendations – yet to be implemented though – are the Kelkar Committee and the Rama Rao Committee.

The government constituted a committee under the chairmanship of Dr Vijay L Kelkar in April 2004 essentially to examine and recommend changes in the defence acquisition process in order to synergise the efforts of various stakeholders for improving the prospects of indigenous production and utilising the resources available in both the public and private sectors with the objective to strengthen self-reliance in defence preparedness.

## Kelkar Committee Recommendations[28]

The committee recommended acquisition policy reforms with a long-term approach to encourage capability-based entry to promote innovation, efficiency and cost reduction. The committee specifically recommended the setting up of a committee to work out a scheme on the basis of a DARPA model vide Para 6.7(v) of its report. Suggestions by the Kelkar Committee focussed on the following:

- Encouragement to successful private sector companies to participate in defence capability building.
- Employment of offsets as a vehicle to bring in technology and investment.

27. http://pragmatic.nationalinterest.in/2010/01/03/drdo-and-darpa/#sthash.lmutVn39.dpuf
28. Public Information Bureau, http://www.pib.nic.in/release/kelkar

- Creation of synergies between the private and government sectors to promote high technology capabilities.
- Ramping up export of defence equipment and services.
- Defence R&D opportunities with DRDO and industry.

The impact analysis of the recommendations of the Kelkar Committee conducted by a parliamentary committee concluded that the implementation of the measures outlined would result in a high degree of indigenous production and defence preparedness. This would result in greater self-reliance in defence production, benefits in terms of R&D, technology spinoffs, higher industrial growth and exports, increase the competition and provide more employment opportunities as well as cost savings. The initial approach involved constitution of a multi-disciplinary Task Force (TF). The Apex Committee had recommended a need for a multi-discipline TF to prepare the proposal and indicate the fund requirement, modalities of functioning, etc. The TF was to evolve a model for the consideration of the government. However, this was not progressed and an approach paper on the proposed Agency for Defence Science & Technology Advancement and Research (ADSTAR), modelled on the lines of DARPA, was proposed.

In 2009, the P Rama Rao Committee was formed to review the functioning of the country's premier defence R&D organisation, DRDO[29].

## Rama Rao Committee Recommendations Para 7.3.1

"The present grants-in-aid programme of DRDO must be replaced. In its place the committee recommends forming a Board of Research in Advanced Defence Science (BRADS). Following the widely acclaimed model of Defence Advanced Research Projects Agency (DARPA), USA, BRADS should endeavour to access and utilise outstanding human resources available in non-defence laboratories and universities. BRADS should also encourage SMEs to undertake radically innovative research through the Small Business Innovation Research (SBIR) programme".

29. Public Information Bureau, http://www.pib.nic.in/release/Ramaraocommitteereport

## Analysis of Recommendations of Kelkar and Rama Rao Committees

- The recommendations for taking up parallel development on a model similar to the USA's DARPA of the Kelkar Committee report of April 2005 are analogous to the recommendations of the Rama Rao Committee report of February 2008. In the former, the government is to set up a mechanism to work out a scheme for taking up parallel development on a model similar to DARPA. In the latter, the committee recommends forming a Board of Research in Advanced Defence Services following the widely acclaimed model of DARPA. Thus, in essence, both reports underline the need for adopting a model similar to DARPA for meeting the futuristic needs of the defence forces.
- DRDO's mandate[30] contained in the "Allocation of Business Rules" includes:
  - Scientific research, design development, testing and evaluation in fields relevant to national security.
  - Building relationships with research organisations within and outside the country.
- It is considered prudent and feasible to progress implementation of both the above recommendations as suggested in the Report of the Review Committee, "Redefining DRDO, February 2008".

## Acceptance of Rama Rao Committee Report

On May 14, 2010, the government announced the acceptance of the report of the Rama Rao Report Implementation Committee headed by the Defence Secretary. The salient aspects are as under[31]:

- Establishment of a Defence Technology Commission (DTC) chaired by the Hon'ble RM and supported by a Secretariat located at DRDO HQ. The Secretariat is composed of both DRDO scientists and Service officers. The DTC includes the three Service Chiefs and Chief of Integrated Defence Staff (CIDS).
- Decentralisation of DRDO management by forming seven technology domain-based centres under DG Centres. The DRDO Management

30. http://www.wikepedia.org/wiki/Defence_Reearch_and_Developmenmt_Organisation
31. http://www.defencenow.com/news/870/defence-technologynology-commission-in-final-stages.html

Council to be headed by the DRDO Chairman with seven DG Centres and four CC (R&D) at DRDO HQ besides an Additional FA (R&D) under him.

- Making DRDO a leaner organisation by merging some laboratories with other similar public funded institutions.
- Revamping of the entire Human Resource (HR) structure of DRDO by appointing a reputed HR expert as consultant.
- Establishing a commercial arm of DRDO with seed capital of Rs 10 crore.
- Industry players to be selected through a transparent process to increase private participation in DRDO activities.
- A mechanism to ensure accountability of individual laboratory Directors while ensuring full autonomy to laboratories for Science and Technology (S&T) initiatives to be introduced.
- Five percent of the DRDO budget for three years to be allocated for rejuvenating research.

# Chapter 7
# Recommendations

- One of the primary reasons for DRDO's failing has been the institutional gap between the research body and the armed forces. DRDO needs to institute a dedicated board for research, a commercial arm on the lines of the Indian Space Research Organisation's (ISRO's) ANTRIX and a key Services Interaction Group (SIG) to involve the armed forces in projects from the inception stage. The SIG, headed by a three-star Services officer, may function as the main coordinator between DRDO and Service HQ for all projects, with the primary mandate to address the problem areas and build "bridges of friendship" with the research body. The SIG may have Major General equivalent officers from all three Services, each responsible for developmental projects of their respective Service.
- DRDO should focus on design and development issues, with some inherent research requirements. However, the essential futuristic R&D activity required for the Services would need to be steered through implementation of the DARPA model for the Indian defence R&D system.
- There is strong case for the Services to go beyond the DRDO / DPSU paradigm in the foreseeable future. Implementation of the Indian adoption of the DARPA model will be major step in that direction.
- Incorporation of the DARPA model for the Indian defence R&D system. A tri-Service nucleus with DRDO representation at Headquarters Integrated Defence Staff (HQ IDS) to be formulated to steer the national defence R&D activities (including DRDO, private and public sectors and academia) towards meeting the operational requirements of the Services. The funding modalities, selection of projects and project monitoring should be in the domain of Service HQ. HQ IDS could focus on dissemination and sharing of technology inputs, undertaking initial exploratory interactions with R&D agencies and provision of a suitable platform for interaction. HQ IDS may also address issues of commonality among the three Services, interoperability and steering of joint Service projects.

- Setting up of a national Task Force (TF) for identification, sponsorship, funding and incentivisation of defence R&D technologies to be undertaken by the academia and private sector. The TF should audit and benchmark the national defence technology threshold and identify critical and emerging technologies for future defence requirements by undertaking a technology scan and technology forecasting using advanced techniques such as the Delphi technique, trend extrapolation, preclusive indicators and contextual mapping.

## End State Deliverables

- Fast track defence technology application/product development for meeting the future operational requirements of the Services.
- Increased accountability of R&D programmes to the Services.
- Reduction in existing bureaucratic and hierarchical R&D projects causing delays.
- Involvement of all stakeholders in defence R&D.
- Enhanced interface between national defence R&D effort and technologies to be employed for military applications.

# Chapter 8
# Conclusion

The resurgence in Indian industry today offers scope for its greater involvement in the defence sector due to the availability of the requisite skills and infrastructure for undertaking defence production and even R&D in some fields. Over the last four decades, considerable resources have been invested in setting up our defence R&D infrastructure through which we have achieved enhanced capacities in the defence sector. India is also witnessing a significant growth in the private sector with many industries becoming global players. There has also been a shift in the role of the private sector entities in the field of indigenisation. From the role of suppliers of raw materials, components, sub-systems, they have now become partners and manufacturers of complete advanced systems.

DRDO must concentrate on critical areas which best fit its existing human resource, technical capability and established capacity to take up new projects.

The Kelkar Committee recommendation for taking up parallel development by a DARPA-like model needs to be urgently implemented which will complement the efforts of DRDO.

# Appendix A

List of the DARPA projects presented on the technology website:

DARPA Avatar Program Coming, But Will Soldiers Want To?
A programme to recreate Avatar, a movie in which a human is "uploaded" to a robot?

DARPA Shredder Challenge Won!
Is it possible to reconstitute shredded documents?

DARPA's 'Biometrics-At-A-Distance' Knows You By Heart
Demonstrates the ability to collect, localise, and evaluate physiological signals (e.g., heart rate) at distances greater than 10 metres.

Warrior Web: Superman Underwear From DARPA
DARPA is looking for a wearable suit that can help protect war-fighters.

ACTUV Game From DARPA Seeks Ender Wiggin
Available to the public for free download.

Robust Automatic Translation of Speech DARPA's Universal Translator
Brings together its diverse speech translation efforts into an all-in-one package.

DARPA Cyborg Insects With Nuclear-Powered Transponders
The goal of the radioisotope transmitter work is to power the insects that the group is developing for DARPA.

Smart Video Cams - DARPA's Mind's Eye
A smart camera, with sufficient visual intelligence that it can report on activity in an area of observation.

And DARPA Shall SMITE The Wicked
Dynamically forecast when deadly moles deep within government departments will likely strike.

Pharmed Blood Is DARPA's Tru Blood
Mass-produced synthetic blood for transfusions.

Cyborg Insect Communication System Planned By DARPA
Now being designed to communicate with each other by modulating their usual calls.

DARPA's Restorative Injury Repair Dream
They'd like to see a device that can repair skin - as well as nerves and bones.

Fracture Putty for Compound Fractures
Fracture putty could rapidly restore a patient to ambulatory function while normal healing ensues, with dramatically reduced rehabilitation time.

'Iron Curtain' Active Protection System
When activated by an approaching projectile, the Iron Curtain takes it out. Remarkable DARPA video below.

iRobot's ChemBot Blob: JSEL Takes Baby Steps
A robot based on Jamming Skin-Enabled Locomotion (JSEL).

Harvesting Power From Flying Insects
The first successful mechanical energy scavenging from flying insects.

Stealthy, Persistent Perch and Stare UAVs
The intent is to develop the company's one-pound, 29-inch wingspan battery-powered Wasp unmanned system.

InfoChemistry And Self-Folding Origami
These machines use cutting-edge mathematical theorems to fold themselves into virtually any three-dimensional object.

Legged Squad Support System Monster BigDog Robot

DARPA wants a new "robotic mule" to carry gear for soldiers in the field.

Handheld Fusion Reactors Planned

Furthermore, DARPA thermal isolation techniques will enable high efficiency beams to power converters, perhaps making chipscale self-sustained fusion possible.

Silent Talk 'Telepathy' For Soldiers

"...allow user-to-user communication on the battlefield without the use of vocalized speech through analysis of neural signals."

TASC - DARPA's Psychohistory

The agency is seeking white papers to fuel the development of a scientific approach to predicting the actions of large masses of people.

Guided Bullets By Exacto From DARPA

How is it possible that a bullet could redirect its own course in mid-flight?

DARPA Seeks Self-Repairing Hunter-Killers?

Tests to date have seen small aerial robots lose large chunks of themselves to hostile fire, yet carry on with their mission.

DARPA Gandalf Project And Philip K. Dick

A new Defence Department project to locate enemies precisely, and target them, by phone.

EATR - DARPA's Energetically Autonomous Tactical Robot

A project to develop a robotic platform able to perform long missions while refuelling itself by foraging.

You Can't Hide From DARPA

Harnessing Infrastructure for Building Reconnaissance (HIBR).

Squishy SquishBot ChemBots Desired By DARPA

ChemBots are soft, flexible robots that are able to alter their shape to squeeze through small openings and then regain their full size.

Fracture Putty For Compound Fractures - DARPA

An alternative to today's standard treatments, which often lead to further complications, and are not fully load-bearing,

Submersible Aircraft - DARPA's Flying Sub?

The minimal required airborne tactical radius of the sub-plane is 1,000 nautical miles (nm).

MAHEM Metal Jets Like Clarke's Stiletto Beam

To create Compressed Magnetic Flux Generator (CMFG)-driven magneto hydrodynamically formed metal jets and Self-Forging Penetrators (SFP).

Precision Urban Hopper Robot Must 'Stick' Landings

Intended to give wheeled robots an additional edge; the ability to jump up onto or over obstacles up to nine metres high.

Katana Mono-Wing Rotorcraft Nano Air Vehicle

The Katana Mono-Wing Rotorcraft is a coin-sized one-bladed helicopter.

Micro Imagers For Sensing On Nano Air Vehicles

With the impetus toward micro-air and -ground vehicles for military applications, there is a compelling need for imaging micro-sensors compatible with these small platforms.

RESURRECT High-Fidelity Computer Battlefield Simulations

To create high-fidelity computer simulations of in-theatre events for tactical, operational and strategic review

Aqua Sciences Water From Atmospheric Moisture

The programme is focussed on creating water from the atmosphere using low-energy systems.

Shape-Shifting Bomber In Need Of Plowsharing

Shape-shifting supersonic bomber fans are feeling bereft this weekend.

Automated Mammalian Training Devices

The development of an automated mammalian training device would significantly reduce the need for human involvement.

RISE Robot: Six-Legged BIODYNOTICS Runaway

These robots in sensorial environments are being developed by researchers from Carnegie Mellon.

DARPA Vulture Five-Year Flying Wing

The Vulture is intended to fly for periods of up to five years unattended at 65,000 feet.

LSTAT-lite Life Support For Trauma and Transport-lite Demoed

LSTAT has been around since 1999; however, the LSTAT-lite is considerably lighter and more affordable.

LANdroid WiFi Robots

DARPA is soliciting proposals for intelligent autonomous radio relay nodes.

HI-MEMS: Control Circuits Embedded In Pupal Stage Successfully

Researchers have succeeded in implanting electronic circuit probes into tobacco hornworms as early pupae.

HI-MEMS: Cyborg Beetle Microsystem

The University of Michigan team has successfully created a cyborg unicorn beetle microsystem.

Carnegie Mellon's Boss Wins DARPA Urban Challenge

Carnegie Mellon's Boss, an autonomous Chevy Tahoe, was declared the winner.

2007 DARPA Urban Challenge Videos

The teams will attempt to complete a complex 60-mile urban course with live traffic in less than six hours. Now, the videos.

DARPA Wants Exoskeletons

DARPA thinkers are saying that may be humans themselves need an upgrade.

DARPA Urban Challenge For Autonomous Vehicles

The Urban Challenge consists four sets of vehicle behaviour requirements.

IR Chemical Communication Graffiti Tags Wanted By DARPA

The Chemical Communications (ChemComm) programme objective is to encode and transmit information in a rapid and covert manner.

Hybrid Insect MEMS Sought By DARPA For Bug Army

HI-MEM-based bug armies? Our friends at DARPA seem to have cyborgs on the brain.

DARPA's 'BigDog' Robot Now In Puppy Stage

Project seeks to create algorithms that help multi-legged platforms learn to walk in varied terrain.

DARPA Urban Challenge - KITT, Put Up Or Shut Up

Autonomous ground vehicles will take to a mocked-up urban area to negotiate a 60-mile course.

Star Wars Binoculars A Cognitive Technology Threat Warning

They've dubbed the device "Luke's Binoculars," after the device used by Luke Skywalker in the original Star Wars movie.

DARPA Radar Scope Can Sense Thru Walls

Hand-held radar scope can provide troops with an ability that was formerly the province of science fictional superheroes alone.

BigDog Quadruped Robot Update

Good progress on Ray Bradbury's mechanical hound from *Fahrenheit 451*.

DARPA Wants Exoskeletons

In a briefing today on GovExec.com, a variety of projects from DARPA (Defence Advanced Research Projects Agency) demonstrate that some science fiction thinking is good.

Shark Cyborgs On DARPA Remote Control

In those Jaws movies, the shark seemed like it was out to get you. DARPA makes this dream come true.

Bradbury's Mechanical Hound and DARPA's BigDog Robot

In his chilling 1953 novel, *Fahrenheit 451*, Ray Bradbury created the mechanical hound, a robot that accompanied the firemen and helped with their work... DARPA has made a multi-million dollar investment in the soldier of the future's best friend - BigDog.

DARPA Seeks Metabolic Dominance

DARPA has initiated a new programme called "Metabolic Dominance" to assure that soldiers have superior physiological qualities. Frank Herbert had the answer sooner, though.

DARPA's Walrus and Griffith's War-Balloons

Not your great-grandfather's airship, the Walrus will be able to lift a fighting force.

DARPA's Radiation Decontamination (And 'Doc' Smith's Dekon)

DARPA and a host of scientists are working on decontamination techniques for dirty bombs.

Obtaining Unobtainium at DARPAtech 2004

DARPA searches for impossible materials - unobtainium - and is succeeding.

Springtail EFV-4B Personal Air Vehicle From Trek Aerospace

The Springtail EFV-4B Personal Air Vehicle (PAV) is a fourth-generation Vertical Take-Off and Landing (VTOL) craft powered by a single engine.

Trauma Pod Battlefield Medical Treatment System

DARPA has awarded a $12 million contract to develop an automated medical treatment system that can recieve, assess and stabilise wounded soldiers immediately following injury. The trauma pod is used to treat soldiers on the battlefield using advanced

Cormorant Submarine/Sea Launched MPUAV

The Cormorant submarine and sea launched vehicle concept may remind you of science fiction glories past.

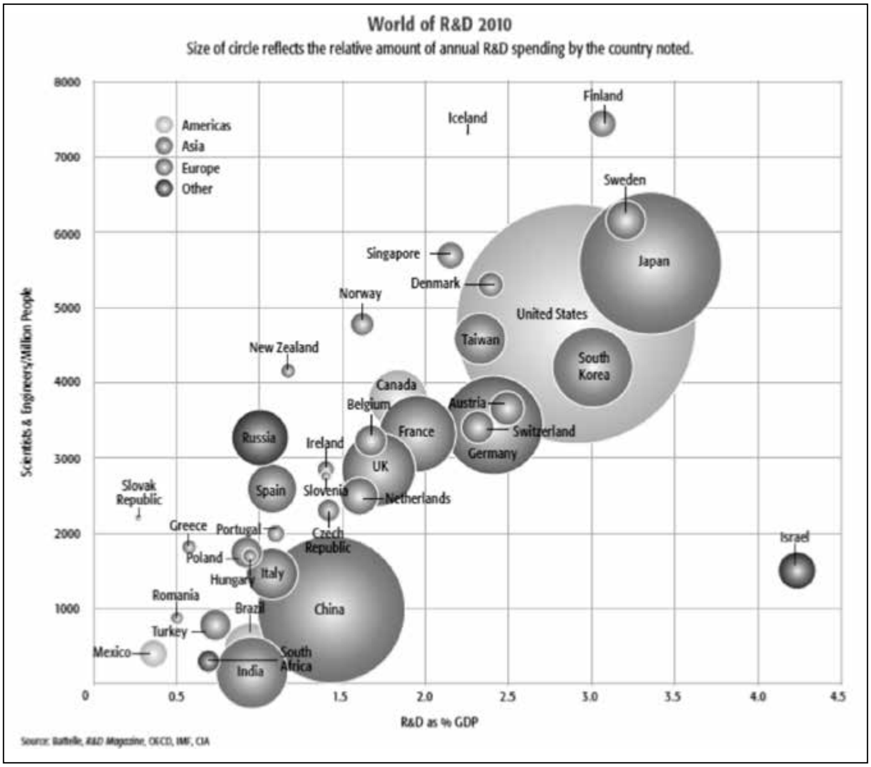
Terminator Tether - EDT Solution To Space Debris Update

Studies have shown that low Earth orbit is not a limitless resource and should be managed more carefully. Some sort of debris-mitigation measures are needed to solve the problem of old, unusable satellites and space junk.

HELLADS: Lightweight Laser Cannon

Ultra-light high energy liquid lasers

## Appendix B


World of R&D 2010
Size of circle reflects the relative amount of annual R&D spending by the country noted.
Americas
Asia
Europe
Other
Scientists & Engineers/Million People
R&D as % GDP
Finland
Iceland
Sweden
Japan
Singapore
Denmark
Norway
United States
Taiwan
New Zealand
South Korea
Canada
Belgium
Austria
France
Switzerland
Germany
Russia
Ireland
UK
Slovak Republic
Spain
Slovenia
Netherlands
Greece
Portugal
Czech Republic
Israel
Poland
Hungary
Italy
Romania
Brazil
China
Turkey
Mexico
South Africa
India
Source: Battelle, R&D Magazine, OECD, IMF, CIA