Defence Science Journal, Vol. 60, No. 3, May 2010, pp. 259-270

Identification of Military-related Science and Technology

Ronald N. Kostoff and Sujit Bhattacharya*

The MITRE Corporation, 7515 Colshire Drive, McLean, VA 22102, USA
**National Institute of Science, Technology and Development Studies (NISTADS), K.S. Krishnan Marg, New Delhi-110 012*
E-mail: sujit_academic@yahoo.com

ABSTRACT

A proof-of-principle demonstration for extracting military-related technologies from a country's total technology publications has been performed, and applied to the Indian science and technology literature#. The method is general and can be applied to the extraction of any meta-category (e.g., intelligence-relevant technologies, infrastructure-relevant technologies, etc) which is not easily obtained from document clustering or factor analysis. The methodology for identifying relevant literature on military science appears to provide credible results. The volume of literature retrieved will vary depending on how strongly relevant is the desired literature. For the same definitions of 'military relevant', the volume of India's literature in the *Ei Compendex* database was an order of magnitude less than that of the USA or China.

Keywords: India, text mining, military-relevant, pattern extraction, defence infrastructure

1. INTRODUCTION

Identifying military-relevant technologies from the science and technology (S&T) literature is a query development issue. While identification of records that contain obvious military terms (aircraft carrier, ballistic missile, etc) is relatively straight-forward, identification of the technologies associated with those terms is much more complex. Some type of pattern extraction/association approach between the military concepts and the related technologies is required. The military concept-technology concept linkages can be direct (e.g., phrase co-occurrence[1]) or indirect (e.g., latent semantic analysis[2], latent Dirichlet allocation[3], citation linking[4], organisational linking, journal linking, author linking, etc).

In a previous series of papers and reports[5-10], an assessment of India's open literature in science and technology was done. It was shown that, for the 15 year period from 1980 to 1995, India's growth in the open literature remained stagnant, but in the decade since 1995, it has started to increase. Because in those studies, a ready mechanism for identifying which S&T was military-related, and the strength of the relationship was not used, they decided to undertake a proof-of-principle demonstration of a methodology that would identify which of India's S&T was military-related. The present paper reports the first phase of the overall demonstration, namely, identification of India's military-identifiable and strongly military-relevant research.

2. BACKGROUND

There is modest literature on text-based pattern extraction relative to non-text. Lim[11], *et al.* framed the problem accurately from user's perspective. They observed that many information extraction systems use a pattern-matching approach, but the patterns have to be created for each target task or target domain. To improve information extraction systems and make these portable to various domains, a mechanism is required to create patterns easily. They proposed a method to automatically construct verb class and patterns from an untagged corpus.

Yoon and Kerschberg[12] discovered association rules based on a user's query, including pattern extraction from both positively- and/or negatively-related query views; pattern association across attributes to enhance the semantics of patterns, while performing pattern spanning within an attribute domain to enhance the supportiveness of the resulting pattern. Zheng[13], *et al.* used a single-link clustering approach, and extracted textual patterns from the separate clusters. While these automated approaches provide reasonable results for extracting interesting associations from large volumes of text in real time, the linkages do not have adequate specificity for the type of detailed analysis desired in the present study.

3. METHODOLOGY

The following two-step approach was taken for the present paper. In the first step, an iterative relevance feedback approach was taken to generate a query to retrieve military-identifiable documents. These are documents that are unmistakably military-oriented. These contain terms like artillery, aircraft carrier, fighter aircraft, weapons of mass destruction, etc. In the second step, an iterative relevant feedback approach was taken to generate a query to retrieve

Received 20 August 2009, Revised 20 October 2009

strongly military-related documents. These are documents that may or may not contain the military-identifiable terms, but the technologies within these documents are those that are strongly associated with the military-identifiable documents.

In the first step, term like military was used to query the abstract and keyword fields (in some cases, controlled vocabulary fields as well), records were retrieved, phrases and phrase combinations that were unmistakably military (e.g., artillery, aircraft carrier, etc) were extracted, added to the query, and the process was repeated until convergence. Initially, organisation names (e.g., XXX military academy) were queried as well, but many of the records retrieved were not sufficiently military-identifiable, so the organisation/address field was not accessed further.

The second step proved to be much more difficult. The objective was to identify technology text patterns that occurred in the military-identifiable records, and to add these text patterns to a query that would retrieve records containing military-relevant technologies. Unfortunately, there were many types of technology text patterns that could be extracted from the military-identifiable records, and these different text patterns resulted in different strengths of relationships between the technologies in the records retrieved and their linkages to the military application.

For example, the simplest pattern was a list of technology phrases extracted from the military-identifiable records by straight-forward phrase frequency analysis. This list was obtained by visual inspection of all phrases contained within the military-identifiable records, above a pre-selected threshold frequency of occurrence. Selected phrases were entered into the *Ei Compendex* database search engine, and the records retrieved were sampled for military relevance. In many cases (e.g., 'information technology', 'neural networks', 'signal processing'), only a small fraction of the retrieved records had a direct relationship to the military application, although one could argue that for example 'signal processing' expertise focused on a non-military application could be readily transferable to a military application. The retrieval volume was quite large, given the broad coverage of the technologies identified.

The next simplest pattern was a variant of the first, whereby more detailed stand-alone phrases were extracted. Thus, instead of extracting 'signal processing' as above, a specific variant like 'radar signal processing' that might be more targeted to a military application was extracted. A query spanning six pages in length was generated, consisting of ~1600 words or approximately 500-600 long multi-word phrases. Again, hundreds of thousands of records were retrieved, with perhaps a slightly higher fraction of military-relevant documents, but still relatively low.

The final two patterns examined were phrase combinations. The first combination approach was inspired by the first author's literature-related discovery methodology, whereby document clustering or factor analysis was performed on the military-identifiable documents, and combinatorials of the key technologies in each cluster or factor was used as a query. This approach yielded records somewhat closer to what was desired, but still of insufficient military specificity.

The second combination approach (which was used for the present study) was derived as follows:

- A list of the key technologies in the military-identifiable records was generated by visual inspection of the phrases in these records (e.g., 'signal processing', 'information technology', 'synthetic aperture radar', 'neural networks', 'wireless networks', etc).
- A second list of desired functions or actions or more specific technologies was generated by visual inspection of the phrases in these records (e.g., 'target identification', 'intrusion detection', 'obstacle avoidance', 'target recognition', 'active jamming', etc).
- The two lists were matrixed against each other, and the potential combinations reflected by the contents of each cell were broad technologies focused on achieving a military-driven mission (e.g., 'signal processing AND target detection', 'genetic algorithms AND feature extraction', etc). This approach narrowed the retrieval considerably to strongly military-relevant technologies.

Thus, it appears that classes of technology document retrievals need to be defined with different degrees of military-relevance. This paper is limited to retrieving the military-identifiable and strongly military-relevant technologies for India. In future studies, some of the broader patterns described above might be used for the retrieval (depending on the study objectives), in which case the additional technologies retrieved might have to be classified as military-relevant or moderately military-relevant.

It should be noted that while the query component for retrieving military-identifiable records will almost always retrieve records that are unmistakably military-related, the query component for retrieving strongly military-relevant technologies will usually, but not always, retrieve records that are unmistakably military-related. These combinations of technologies, that are characteristic of strongly military-related records, can be used for non-military purposes. For example, the combination of technologies required to identify and track surface warships could also be used to identify and track selected animal herds. The key here is that the capability exists for the potential military application, even though the record may not indicate the military application.

4. DATABASES USED

It was desired to use a database(s) with the following properties:

- relatively homogeneous records;
- peer-reviewed journals and conference proceedings;
- strong military applications component; and
- strong applied technology component.

The first choice was the *Science Citation Index* (SCI), because of its strong bibliometric component, and its citation capability. However, the SCI is a mainly basic research database, with some applied research, and has neither the terminology nor the coverage of the advanced military applications (nor the associated advanced technology development) that was needed for the initial phase of this study.

It was then decided to use the *Ei Compendex*, even though it has no citation capability, and its bibliometrics are not as comprehensive as those of the *SCI*. The *Compendex* has good coverage of military and other advanced technologies, and the journals and conference proceedings are of high quality. A problem encountered with this database was that extensive country and institutional data cleanup was required, and the cleanup process was manual and labour-intensive.

The results presented must be viewed in the context of India's science and technology infrastructure, both at the higher planning/allocation level and at the execution/performer level. To provide that context, a summary of this science and technology infrastructure has been presented.

5. INDIA'S S&T AND R&D INFRASTRUCTURE

India has a huge R&D infrastructure with 400 national laboratories, 1300 recognised in-house industrial units, besides several government departments and private institutions and foundations engaged in scientific research. The R&D work is also undertaken in 358 universities in the country. In spite of this impressive R&D infrastructure in the country, the amount of funds directed for R&D is below 1 per cent of GDP. By comparison, R&D as percentage of GDP in 2006 was 1.42 per cent for China, 2.62 per cent for USA and 3.39 per cent for Japan[14]. Beyond all these percentages, the allocations to technical areas would need to be examined to provide a fuller context, which is beyond the scope of the present study.

Despite relatively low R&D share in GDP, positive trends are seen for India. The National India R&D expenditure in 2005-06 was ~$5.98B and has been projected to attain a level of $6.846 B in 2006-07 and $7.852 B in 2007-08[15]. The share of R&D expenditure as a percentage of GNP has also increased from 0.58 per cent during 1990-91 to 0.80 per cent during 2002-03, to 0.89 per cent in 2005-06[16]. Also, there are approximately 500 foreign R&D centres that have been established in India; majority of these in the last few years. Some of these that have made significant investment in R&D, are involved in frontier areas of research, and have developed extensive linkages with Indian universities and research institutions.

India's major source of R&D funding comes from government (approx. 75 % on an average). This is in stark contrast with developed and some emerging economies (such as China) where the involvement of Government in R&D spending is 30 per cent to 40 per cent (lower/upper end). Industry is the major driver of R&D activity in these countries and this is cited as the plausible reason for these countries attaining between 2 per cent to 4 per cent R&D expenditure as a percentage of GNP. China is a case where R&D as percentage of GNP is almost 1.5 per cent with the industry contributing almost 57 per cent towards overall R&D investment in the country[17].

Approximately 86 per cent of the Indian Central Government R&D expenditure during 2005-06 was incurred by 12 major scientific agencies. The share of Defence Research and Development Organization (DRDO) among the 12 scientific agencies was 34.4 per cent. In absolute terms, this amounts to $1.756 B. Thus, the Government's priority for defence research can be observed clearly.

Extramural funding is an important component of strengthening R&D activity. Major scientific agencies are involved in extramural funding. The extramural R&D funding commitment by Central government S&T departments/agencies was $0.242 B in 2005-06[18]. There were 3569 projects approved for funding during 2005-06.

5.1 Defence Research Infrastructure

India's formal military research is primarily undertaken by DRDO which is under Ministry of Defence. The DRDO operates through a network of around 52 laboratories and establishments located nationwide and manned by over 34,000 personnel, including about 16,000 scientific/technical persons. As illustrated earlier, in comparison to R&D allocation across different scientific agencies, defence R&D has a high priority (accounts for approx. 35 % of total allocation to scientific agencies). However, in terms of share within the defence budget, defence R&D constitutes only 6 per cent ($1.338 B in 2007-08) of the total defence budget[19]. In contrast, major military powers spend a much higher proportion of their budgets on military R&D. For instance, the United States spends around 16 per cent of its defence budget (excluding supplemental funding for ongoing operations in Iraq and Afghanistan) on research, development, test, and evaluation, and its late-2008 pre-stimulus estimated defence R&D (~$86 B) is about 60 per cent of total R&D (~$147 B) in the Federal R&D portfolio. But one has to keep in consideration that India's case is different from USA, as government accounts for approx. 75 per cent of India's R&D expenditure whereas it is only approx. 30 per cent in the case of USA.

The DRDO has identified twenty topics as thrust areas for research (http://www.drdo.com). These twenty topics are: Stealth (includes radar absorbing materials and structures, air frame shaping); *GaN* devices (high-frequency/high-temperature applications); *SiC* devices (includes high-power electronics/high-frequency devices for tele-communication uses), soldier-as-a-system (clothing, communication, and weapons system), nanotechnology, TeraHertz (detection of hidden explosives/drugs/weapons, detectors and sensors), sensors, laser technology, functional materials, solar energy, multiband conformal antennas, gas turbine technologies, hypersonics, nanophotonics, high-energy materials, high-power microwaves including EMP, network-centric operations, MEMS (MEMS-based micro-sensors and actuators, drug delivery system), high-efficiency aerodynamics and active protection system (radar system, detection of incoming threat/early warning). The DRDO has strict time schedules; thus, it does more developmental work than research in its own R&D units. There is a committed effort for capability enhancement through extraneous linkages. Also, DRDO is using the linkage model for addressing the thrust areas. The institutional channels used by DRDO for academic interactions are: Extramural funding, CARS, Centres of excellence, various Research Boards.

There are no separate provisions in public-funded universities and civilian laboratories for defence-related research. There has been a proposal for setting up a specialised defence university but that is yet to take final shape. However, DRDO is actively engaged in stimulating military research in universities/engineering schools and research centres. The intra-research linkages are intended to provide needed inputs for addressing specific goals as well as help DRDO in long-term futuristic frontline research that can create state-of-the-art weapon systems and other high-end military applications. The desired objective is to create a network of specialised centres in universities/research organisations and develop skilled manpower that can synergise military research in India. Universities (especially engineering schools of repute) in the country have been engaged in research that can have dual applications (civilian as well as defence). Some of the universities (IITs, IISc, Anna University) have interdisciplinary/multidisciplinary schools that have strong linkages with defence laboratories such as cryogenic engineering, electronics and electrical communication engineering at IIT-Kharagpur. Among CSIR laboratories, especially National Aeronautical Laboratory (NAL) has active collaboration with DRDO. Two other public-funded establishments, namely, Indian Space Research Organization (ISRO) and Department of Atomic Energy (DAE) have strategic linkages with DRDO. Strong horizontal linkages of DRDO laboratories with ISRO have been instrumental in considerable success of DRDO's missile development programme; e.g., advanced long range guided missiles, etc.

The main instrument of DRDO's linkage with universities is through extramural funding. A broad analysis of four years of extramural funding by DRDO (2002-03 to 2005-06) shows that the funding was mainly in 'Engineering and Technology (E&T)[18,20]. Within E&T, AR&DB (Aeronautical Research and Development Board) provides major funding. The AR&DB is also involved in creating centres of excellence and capital investments (for example at IIT-Mumbai and IIT-Kharagpur). Table 1 highlights the funding pattern in E&T.

Table 1 clearly shows that IITs and IISc account for majority of the projects. Physical sciences, and to some extent, Chemical sciences are other areas where DRDO is providing extramural funding. In these areas along with IIT's and IISc, one finds other reputed universities (such as Anna University, Jadavpur University, some NITs) are also attracting funding.

Table 1. Extramural funding pattern in engineering and technology (2002-2006)

Year	No of projects funded in E&T	No. of projects funded by AR&DB	Organisations receiving major funding from AR&DB
2002-03	50	24	IIT-19, IISc-10
2003-04	44	36	IIT-17, IISc-5
2004-05	38	31	IIT-16, IISc-4
2005-06	73	39	IIT-15, IISc-9

6. RESULTS

Military-related research published in the open literature would show the broad capabilities of different institutions in military-related research. It would also show that upto what extent the published research thrust areas match with the thrust areas identified by DRDO. However, publication activity may not show the strategic component of military research as it is covered by confidentiality and non-disclosure agreements.

6.1 Numbers of Military-relevant Records

The full query of matrixed terms (~1700 two or three-word terms, representing about 6,000-8,000 term combinations) was entered into the *Ei Compendex* search engine, and about 47,000 records were retrieved for the 2006-mid-November 2008 time frame, for all countries. The records for about six journals were expunged, since these were viewed as reporting-type records rather than original R&D or reviews, resulting in a final total of about 42,000+ records. Extensive manual affiliation cleanup was required to assign records to the appropriate countries.

There were 1,064 records whose primary authors were from India. To place this in context, there were 12,323 records from USA, 10,511 from China, and 321 from Iran. These records were in the range of 2-3 per cent of total uncleaned publications retrieved. To get more accurate fractions, the total *Ei Compendex* of millions of records over this time period would have to be retrieved and manually cleaned, a task beyond the scope of this study.

6.2 Most Prolific Authors

The Indian authors appearing most frequently have been shown in Table 2. Their primary institutions and main research themes are included as well. The theme summary based on all the keywords is shown under the author's name, and the high frequency keywords are shown in the last column. The main institutions represented are DRDO-Life Sciences (7), DRDO-Armaments (3), and Annamalai University (3). Chemical warfare and energetic materials seem to be the most frequent themes of the prolific publishers.

6.3 Most Prolific Institutions

The Indian institutions appearing most frequently are shown in Table 2. Some institutions are aggregates of multiple campuses, others represent single campuses. The six main Indian Institute of Technology campuses are shown separately, as is the Indian Institute of Science

Table 2. Prolific Indian Authors

# Rec	Author	Institution	Keywords
9	Pardassani, D (Chemical Warfare)	DRDO-Life Sci	Solid-phase extraction method; extraction solvent; extraction efficiencies; alkylphosphonic acids APAs; target analytes; nerve agents; microwave irradiation; loading capac ity; chemical warfare agents CWAs; full scan; chemical weapons; OPCW
9	Raol, JR (Imaging)	NAL	Image registration; simulation software; simulated annealing SA; principal component analysis; performance metrics; non -linear systems; measurement noise; Kalma n filter; image fusion; data fusion; fuzzy logic; fused image; fault diagnosis; extended Kalman filter; acoustic signal; automatic target recognition
9	Dubey, DK (Chemical Warfare)	DRDO-Life Sci	Solid-phase extraction method; extraction solvent; extracti on efficiencies; alkylphosphonic acids APAs; target analytes; nerve agents; loading capacity; chemical warfare agents CWAs; full scan; chemical weapons OPCW; chemical warfare agents
8	Balasubramanian, V (Structural Materials)	Annamalai University	Military vehicles; road tankers; transportable bridge girders; railway transport systems; light weight structures; gas tungsten arc; poor resistance; fusion zone grains; gas metal arc; current pulsing leads; hot cracking; tensile properties; weld fusion zones; w eld metal solidification; equi -axed grain structure; exhibit coarse columnar grains
8	Singh, B (Chemical Warfare)	DRDO-Life Sci	Reaction products; surface area; sulphur mustard; sulfur mustard; degradation products; transmission electron microscopy; mois ture content; electron microscopy; flow rate; energy dispersive analysis; ambient temperature; zinc oxide; chemical warfare agent; X -ray diffraction
7	Telewar, MB (Energetic Materials)	DRDO-Armaments	Thermal decomposition; oxygen balance; high explosives ; tensile strength; thermal analysis; shock sensitivity; pentaerythritol tetranitrate PETN; gun propellants; chemical stability
7	Gupta, AK (Chemical Warfare)	DRDO-Life Sci	Solid-phase extraction method; extraction solvent; extraction efficiencies; alkylphosphonic acids APAs; target analytes; nerve agents; loading capacity; chemical warfare agents CWAs; full scan; Chemical Weapons OPCW; chemical warfare agents
6	Asthana, SN (Energetic Materials)	DRDO-Armaments	Thermal decomposition; shock sensitivity; h igh explosives; tensile strength; gun propellants; thermal stability; thermal properties; molecular level; activation energy; underwater shock wave
6	Kanaujia, P (Chemical Warfare)	DRDO-Life Sci	Solid-phase extraction method; extraction solvent; extracti on efficiencies; alkylphosphonic acids APAs; target analytes; nerve agents; loading capacity; chemical warfare agents CWAs; full scan; Chemical Weapons OPCW
6	Singh, A (Energetic Materials; Ballistics)	DRDO-Armaments	Mechanical properties; gun propellant s; thermal stability; thermal decomposition; thermal properties; oxygen balance; muzzle velocity; ballistic properties; ballistic performance
6	Kumar, CS (Autonomous Control)	IIT-Kharagpur	Underwater vehicles; control law; sensor networks; neural network ; mobile robots; intelligent control; emerging technology; back propagation algorithm; control scheme
5	Kannan, A (Intrusion Detection)	Anna University	Intrusion detection systems; low false alarm rate; labeled training data; intrusion detection system; intrusion detection; data mining; attack scenarios; intrusion detection system IDS
5	Ghosh, A (Remote Sensing)	Indian Stat Inst	Multitemporal remote sensing images; neighboring pixels; multilayer perceptron; unlabeled patterns; neural network; remote sen sing images; multispectral remote sensing images; land cover classification; input image
5	Pal, M (Classifiers)	NIT	Classification accuracy; decision tree; training data set; backpropagation neural network; base classifier
5	Sekhon, GS (Projectile Ballistics/Impact)	IIT-Delhi	Ballistic limit velocity; target plates; target plate; residual velocities; pneumatic gun; finite element analysis
5	Prasad, GK (Chemical Warfare)	DRDO-Life Sci	Reaction products; sulphur mustard; sulfur mustard; transmission ele ctron microscopy; electron microscopy; flow rate; energy dispersive analysis; zinc oxide; chemical warfare agent; X -ray diffraction
5	Bhattacharya, S (Heat Transfer)	IIT-Kharagpur	Heat transfer; throttle valve; mass flow rate; heat transfer rate; gas coo ler; evaporator temperature; transport properties
5	Sekhar, K (Chemical Warfare)	DRDO-Life Sci	Reaction products; sulphur mustard; zinc oxide; alkylphosphonic acids APAs; nerve agents; chemical warfare agents; water samples; surface area; aqueous medium
5	Madhusudhan, RG (Structural Materials)	Annamalai University	Military vehicles; road tankers; transportable bridge girders; railway transport systems; gas tungsten arc; poor resistance; fusion zone grains; gas metal arc; current pulsing leads; hot crac king; weld fusion zones; weld metal solidification; equi -axed grain structure; exhibit coarse columnar grains; rolled plates; grain refinement; shielding gas; filler metal
5	Ghosh, AK (Artillery Tracking and Control)	Annamalai University	Firing site; tr acking error; rocket body; position error; Mach number; flight trajectories; flight control system; artillery shell

Table 3. Prolific Indian Institutions

# Rec	Institution	Keywords
49	IIT-Kharagpur (Modelling and Simulation; Optimization; Networks; Underwater Systems)	Genetic algorithms; mathematical models; computer simulation; neural networks; algorithms; optimization; parameter estimation; vehicles; sub mersible motors; submersibles; underwater ballistics; underwater construction; underwater equipment; underwater structures; water craft
45	ISRO (Remote Sensing; Space Vehicles; Launching Systems; Rocketry)	Remote sensing; satellites; space optics; launchi ng; orbits; sensor networks; vehicles; rockets; computer software; space research; missile launching systems; communication satellites; disaster prevention; reentry; forestry
45	IIT-Delhi (Modelling and Simulation; Fluid and Solid Mechanics; Networks)	Computer simulation; mathematical models; computational fluid dynamics; turbulence; heat transfer; aluminum
44	DRDO-Armaments Cluster (Energetic Materials; Ballistics)	Ballistics; propellants; mechanical properties; binders; smoke; combustion; ammunition
43	NIT (Networks; Optimisation; Remote Sensing; Signal Processing; Power Systems)	Neural networks; genetic algorithms; algorithms; mathematical models; computational methods; particle swarm optimization (pso); computer networks; electric power systems; learn ing systems; signal processing; image analysis; problem solving; classification (of information); heat exchangers; pattern recognition; diesel engines; electric fault location; fault detection; convergence of numerical methods
41	IISc-Bangalore (Simulation; Optimization; Networks; Sensing; Communications; Control; Mechanics)	Computer simulation; neural networks; genetic algorithms; optimization; sensors; computer networks; ordnance; military equipment; problem solving; optimal control systems; finite eleme nt method; routing protocols; routing algorithms
39	Anna Univ (Networks; Sensors; Simulation; Communications; Information Technology; Cybersecurity)	Neural networks; wireless telecommunication systems; sensors; technology; wireless networks; computer simu lation; genetic algorithms; data mining; feature extraction; decision support systems; intrusion detection; computer crime; classification (of information); information management; search engines; energy conservation
38	IIT-Madras (Optimization; Simulation; Fluid Dynamics; Heat Transfer)	Computer simulation; genetic algorithms; optimization; neural networks; reynolds number; laminar flow; mathematical models; aerodynamics; fluid mechanics; heat transfer; support vector machines; turbulent flow; turbulence
36	DRDO-Elec/Comp Sci Cluster (Simulation; Sensing; Signal Processing; Image Analysis; Nanotechnology)	Computer simulation; sensors; mathematical models; algorithms; computational methods; computer networks; signal processing; nanostructured materials
35	IIT-Kanpur (Modelling and Simulation; Flight Dynamics and Control; Heat Transfer; Nanotechnology)	Computer simulation; genetic algorithms; mathematical models; algorithms; parameter estimation; flight dynamics; synthesis (chemical); trajectories; scanning electron microscopy
35	DRDO-Life Sci Cluster (Chemical Warfare; Decontamination; Nanotechnology)	Mass spectrometry; chemical warfare; synthesis (chemical); toxic materials; hydrolysis; gas chromatography; optimization; contamination; extraction; enzymes; adsorption; decontamination; sulfur; antibodies
32	IIT-Bombay (Simulation; Optimisation; Networks; Sensors, Communications; Electronic Devices)	Computer simulation; genetic algorithms; algorithms; optimization; mathematical models; parameter estimation; computer networks; routing protocols; network protocols; boolean functions; bioelectric phenomena; parameter extraction
29	IIT-Roorkee (Optimisation; Modelling and Simulation; Networks; Remote Sensing; Signal Processing; Image Analysis)	Genetic algorithms ; computer simulation; optimization; mathematical models; remote sensing; feature extraction; algorithms; parameter estimation; classification (of information); electromagnetic wave scattering
19	Jadavpur University (Simulation; Networks; Optimisation; Programming; Remote Sensing; Heuristic Methods)	Heuristic methods; computer simulation; algorithms; neural networks; computational methods; database systems
18	NAL (Flight Simulation And Control; Aircraft; Tracking; Imaging)	Algorithms; computer simulation; parameter estimation; estimation; fighter aircraft; trajectories; error analysis; actuators; adaptive control systems; aircraft; real time systems; flight simulators
16	DRDO-Materials groups of Labs (Nanotechnology; Combustion; Ballistics)	Nanostructured materials; nanostructures; ballistics; materials properties; applications

Table 3. Prolific Indian Institutions (contd..)

# Rec	Institution	Keywords
13	DRDO-Aeronautics Cluster (Surveillance; Imaging; Aircraft; Aero/Flight Dynamics)	Algorithms; bandwidth; broadband networks
12	Atomic Research (Blast Simulation; Material Mechanics; Heat Transfer)	Computer simulation; shock w aves; data acquisition; inert gases; heat exchangers; nuclear reactors; equations of state; radiography; hydraulics; surge tanks
12	Annamalai Univ (Metallurgy; Material Mechanics; Alloys)	Grain refinement; gas metal arc welding; welds; heat affected zone; computer simulation; tensile strength; fatigue of materials; genetic algorithms; hydrogen; crack initiation; aging of materials; tungsten; inert gas welding; ferritic steel; welding
12	Coimbatore Inst Tech (Simulation; Networks; Information Extraction)	Computer simulation; neural networks; artificial intelligence; feature extraction; electric fault currents; linear systems; optimization; image classification; computer networks; combustion; computational fluid dynamics; diesel engines; backpropagation; fau lt detection; statistical methods; turbulence; piezoelectric transducers; decision trees
11	DRDO-Missiles Cluster (Modelling and Simulation; Project Management and Quality Control)	Military applications; computer simulation; decision making; mathematical models; project management
10	PSG College of Technology (Networks; Intelligence; Information Extraction)	Neural networks; principal component analysis; competitive intelligence
10	Indian Statistical Institute (Remote Sensing; Information Extraction)	Remote sensing; neural networks; image classification; classification (of information); image processing; data structures
9	DRDO-Naval Cluster (Simulation; Signal Processing; Target Tracking)	Monte Carlo methods; computer simulation; tracking (position); math ematical models; algorithms; estimation; oceanography; covariance matrix; measurement theory; kalman filters; bacteria; sonar; motion estimation
8	IIT-Guwahati (Optimisation; Heat Transfer)	Optimisation; image classification; artificial intelligence; gene tic algorithms; bioelectric phenomena; heat transfer; backpropagation algorithms
7	DRDO-Human Resources (Modelling and Simulation; Optimisation)	Computer simulation; mathematical models

campus. The DRDO was divided into technology thrusts covering multiple institutions, based on the taxonomy provided on its web home page. All the ISRO campuses were aggregated into one designation, as were all the twenty NIT campuses and the two atomic research campuses.

The first column in Table 3 contains the number of records in the database. The second column contains the institution name and the authors' summary of the main technical thrusts for the institution, based on all the keywords associated with the institution and reading of selected abstracts. The last column contains the higher frequency keywords, based on an institution/technical phrase co-occurrence matrix analysis.

A couple caveats are in order here. The technical thrust summaries and keywords are based on a small sub-set of overall institutional capabilities, those deemed strongly military-relevant. Obviously, total institutional capabilities are far broader than those represented here. Also, except for the first few institutions, the numbers are relatively small. There seems to be a sharp drop-off after the top half.

What are the linkages among these institutions? The *Compendex* database does not have data in the form that will identify co-publishing institutions (or co-authoring). However, a cross correlation map can be generated that shows how institutions relate through the common terminology of their publications. Figure 1 is a cross-correlation map of the institutions listed in Table 3. The IITs form a network, but almost all the government research centres (with the exception of DRDO-Human Resources) are outside the network. This is probably due to the specialised nature of the government research centres relative to the more eclectic missions of the research universities, and implies technology development missions in the specialised government laboratories that have little analogue even in the technology institutes. This is all based on the restrictive condition of strongly military-relevant research we imposed initially, and there could always be more overlap between the specialty government laboratories and the technology institutes if this condition was relaxed to military-relevant.

Perhaps Fig. 1 does not fully reflect, but the relational structure appears incomplete. Given the integrated and interoperable nature of the final military product, one would expect linkage among the universities and the government laboratories that are developing the military product, and especially between one or more multi-purpose government laboratories and the specialised laboratories depicted in Fig. 1. These multi-purpose government laboratories would serve to coordinate the research and development, and also serve a second role as the systems integrators of the separate sub-systems being developed by the specialty laboratories. At a minimum, Fig. 1 should have two networks, the university laboratories and specialty

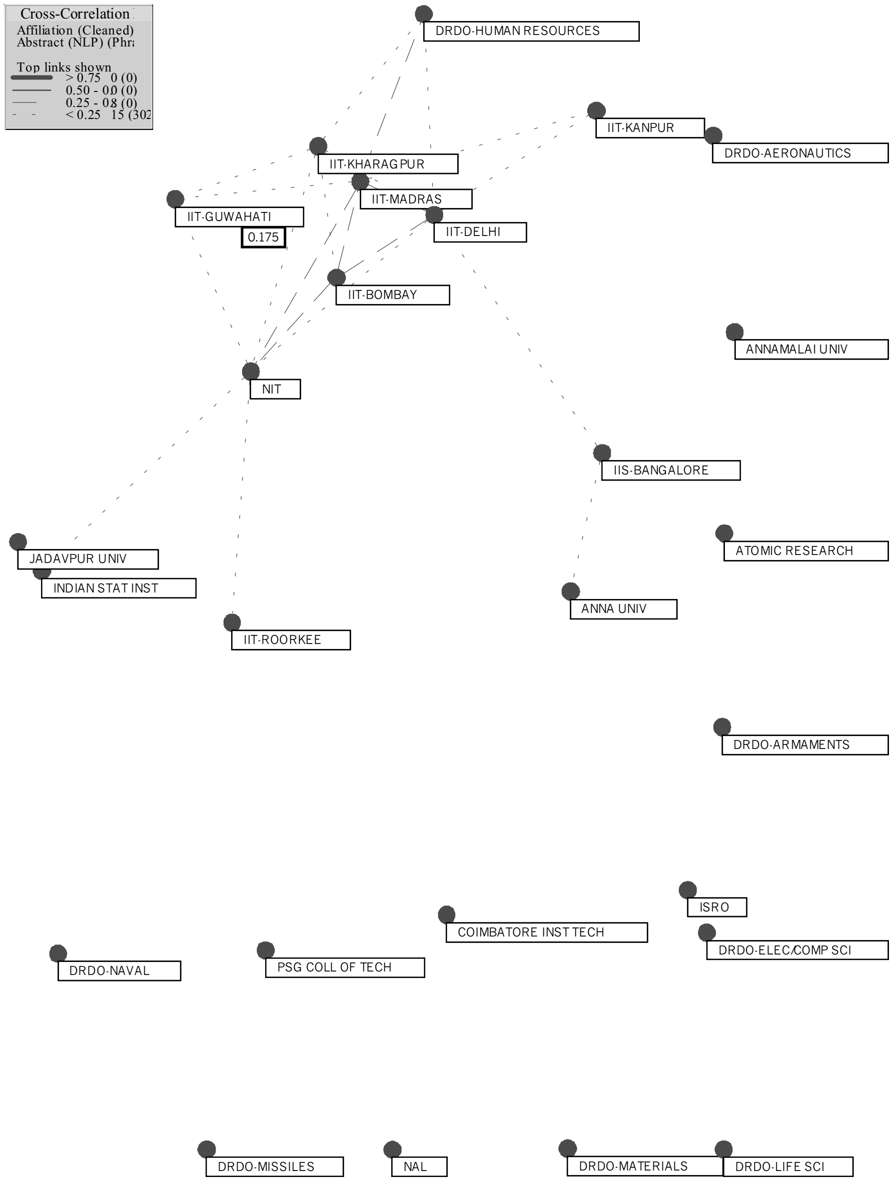

Figure 1. Institution-phrase cross-correlation matrix.

government laboratories, bridged by the multi-purpose government laboratories. This combined network would be a first approximation to a small-world network, and provide a reasonably short path of communication among all the institutions that work for the common defense of India.

6.4 Sources with Most Indian Papers

The journals and conference proceedings containing the most Indian papers are shown in Table 4. The *Defence Science Journal* (DSJ) contains an order of magnitude more papers than the nearest journal/proceedings in line. This should not be surprising. The thrust of the journal is clearly defence, whereas the other journals/proceedings tend to concentrate on specific technologies. Additionally, the DSJ draws most of its authors from India, whereas the nearest journals draw from a broader variety of countries.

6.5 Technical Thrust Taxonomy

The retrieved documents were entered into the CLUTO document clustering algorithm, and the resultant four hierarchical level, 16 category taxonomy is shown in Fig. 2. Only the first and the fourth levels will be discussed; the intermediate level categories will be obvious when the bounding levels are discussed.

The first level is sub-divided into two categories: Physical and Engineering Science and Technology (419 records), and Information Science and Technology (645 records). The Physical and Engineering Science and Technology category covers topics such as chemical agents, explosives, propellants, missile aerodynamics and structures, missile and aircraft heating, and projectile impacts. The main institutional performers in this category are DRDO-Armaments-42, DRDO-Life Sci-32, IIT-Madras-22, IIT-Kharagpur-20, IIT-Delhi-19, IIT-Kanpur-17, DRDO-Materials-16, and the

Table 4. Journals containing most papers

Rec	Source
204	Defence Science Journal
19	Proceedings - 1st International Conference on Emerging Trends in Engineering and Technology, ICETET 2008
19	Proceedings - International Conference on Computational Intelligence and Multimedia Applications, ICCIMA 2007
17	International Astronautical Federation - 58th International Astronautical Congress 2007
17	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)
15	Journal of Hazardous Materials
15	Proceedings of SPIE - The International Society for Optical Engineering
14	International Journal of Remote Sensing
10	Proceedings of ICSCN 2007: International Conference on Signal Processing Communications and Networking
10	Proceedings of the IEEE International Conference on Industrial Technology

main journals are *Defence Science Journal-140, Journal of Hazardous Materials-13, Journal of Chromatography A-8, International Journal of Impact Engineering-6,* and *International Journal of Heat and Mass Transfer-6*. The Information Science and Technology category covers topics such as optimal control, target tracking, wireless networks, remote sensing, intrusion detection, pattern recognition, feature extraction, and classification. The main institutional performers in this category are NIT-36, Anna Univ-34, ISRO-33, IIS-Bangalore-31, IIT-Kharagpur-29, IIT-Delhi-26, DRDO-Elec/Comp Sci-22, IIT-Roorkee-20, IIT-Kanpur-18, IIT-Bombay-18, Jadavpur Univ-17, IIT-Madras-16, and the main journals in this category are *Defence Science Journal*-64, Proceedings-International Conference on Computational Intelligence and Multimedia Applications, ICCIMA 2007-19, Proceedings-1st International Conference on Emerging Trends in Engineering and Technology, ICETET 2008-19, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)-17, International Astronautical Federation-58th International Astronautical Congress 2007-15, Proceedings of SPIE-The International Society for Optical Engineering-12, *International Journal of Remote Sensing*-12, and Proceedings of ICSCN 2007: International Conference on Signal Processing Communications and Networking-10.

Because of the topical differences between the two categories, there is no overlap in the main journals (with the exception of *Defence Science Journal*) and conference proceedings. The only main institutional overlap occur in four of the IIT institutions: Madras, Kharagpur, Delhi, Kanpur. While there is no large-scale overlap in the government research centres because of their specialised nature, it is not clear why there is no large-scale overlap in the NIT.

6.5.1 Document Clustering Algorithm

There were 16 elemental (lowest level) clusters generated by the document clustering algorithm, but only 12 are shown on Fig. 1. Four of the elemental clusters terminated at Level 3 (as shown), and four more elemental clusters terminated at Level 5 (not shown). The 12 clusters shown in Fig. 1 for Level 4 are:

(1) *Chemical Agents (64)*

The focus is on the detection and neutralization of chemical agents that can be used for chemical weapons in chemical warfare, with emphasis on sulfur mustard. The main institutions are DRDO-Life Sci-29, DRDO-Materials-5, DRDO-Elec/Comp Sci-3, and the main journals are *Defence Science Journal*-26, *Journal of Chromatography A*-8, and *Journal of Hazardous Materials*-5.

(2) *Energetic Materials (92)*

The focus is on the synthesis and characterisation of explosives and propellants, with some effort on remediation of environmental impact. The dominant institution is DRDO-Armaments-30, and the main journals are *Defence Science*

Figure 2. Four-level hierarchical taxonomy

Level 1	Level 2	Level 3	Level 4
Physical and Engineering Science and Technology (419)	Chemical (156)	Chemical Agents (64)	
		Energetic Materials (92)	
	Mechanics/ Thermo-dynamics (263)	Heat Transfer (58)	
		Solid and Fluid Mechanics (205)	Fluid Dynamics/CFD (95) Structures/Strength of Materials/Ballistics (110)
Information Science and Technology (645)	Control (417)	Optimal Control/ Tracking (277)	Target Tracking/Kalman Filter (127) Optimal Control/Particle Swarm/ANN (150)
		Wireless Networks (140)	Sensors/Routing Protocols (74) Intrusion Detection (66)
	Imaging (228)	Recognition/ Classification (139)	Classification (89) Pattern Recognition (50)
		Imaging/ Remote Sensing (89)	

Journal-55, *Journal of Hazardous Materials*-7, *Journal of Molecular Structure*-5, *Propellants, Explosives, Pyrotechnics*-2, and *Combustion, Explosion and Shock Waves*-2.

(3) *Heat Transfer (58)*

The focus is on heat transfer and heat production in explosives and propellants, heating of high speed re-entry vehicles and projectiles, and analysis of heat exchangers. The dominant institutions are IIT-Madras-7, IIT-Kharagpur-6, IIT-Delhi-5, DRDO-Armaments-4, and the main journals are *International Journal of Heat and Mass Transfer*-5, *Defence Science Journal*-4, *Journal of Heat Transfer*-3, *International Journal of Thermal Sciences*-3, *Chemical Engineering Science*-3, and *Applied Thermal Engineering*-3.

(4) *Fluid Dynamics/CFD (95)*

The focus is on flows over aerodynamic bodies, flows through aircraft and ground vehicle engines, oceanographic flows, and combustion chamber flows, with special emphasis on computational fluid dynamics. The main institutions are IIT-Madras-10, ISRO-8, DRDO-Elec/Comp Sci-7, DRDO-Combat Vehicles-7, DRDO-Materials-5, and the main journals are *Defence Science Journal*-23, *Journal of Aircraft*-3, Collection of Technical Papers - AIAA Applied Aerodynamics Conference-3.

(5) *Structures/Strength of Materials/Ballistics (110)*

The focus is on welding, fatigue, high strength steels and alloys, projectile impact loading, and explosion resistance. The main institutions are IIT-Kharagpur-10, IIT-Delhi-8, Annamalai Univ- 8, Atomic Research-7, IIT-Bombay-6, IISc-6, DRDO-Armaments-6, and the main journals are *Defence Science Journal*-32 and *International Journal of Impact Engineering*-6.

(6) *Target Tracking/Kalman Filter (127)*

The focus is on tracking of underwater vehicles, airborne targets including aircraft and artillery shells, space vehicles including re-entry phase, counter-tracking systems for defence, with special emphasis on Kalman filtering. The main institutions are ISRO-22, NAL-11, DRDO-Elec/Comp Sci-10, IIT-Delhi-7, IISc-6, Anna Univ-6, and the main journals are *Defence Science Journal*-32 and International Astronautical Federation-58th International Astronautical Congress (2007)-13.

(7) *Optimal Control/Particle Swarm/ANN (150)*

The focus is on neural networks (especially artificial neural networks) and genetic algorithms for prediction and optimal control and design, including some examples of integrating particle swarm optimization, and fuzzy logic control. The main institutions are NIT-15, IIT-Kharagpur -14, IIT-Madras-9, IISc-9, IIT-Kanpur-8, IIT-Bombay-7, Anna Univ-6, The main journals are *Defence Science Journal*-8, Proceedings of the IEEE International Conference on Industrial Technology-6, and *Applied Soft Computing Journal*-5.

(8) *Sensors/Routing Protocols (74)*

The focus is on wireless sensor networks (especially mobile ad hoc networks), emphasising routing protocols, energy efficiency, security protocols, quality of service, and the use of these networks for object tracking. The main institutions are IIS-Bangalore-8, Anna Univ-7, IIT-Kharagpur-3, IIT-Bombay-3, and the main journals are: Proceedings-1st International Conference on Emerging Trends in Engineering and Technology, ICETET 2008-5, *Defence Science Journal*-5, and Lecture Notes in Computer Science (including subseries lecture notes in Artificial Intelligence and Lecture Notes in Bioinformatics)-4.

(9) *Intrusion Detection (66)*

The focus is on intrusion detection and prevention, especially in wireless and mobile ad hoc networks, and on increasing capacity through wideband frequency-sharing CDMA using smart antennas and reduced bit error rate (from interference reduction and cancellation). The main institutions are: IIT-Delhi-6, Anna Univ-6, IIS-Bangalore-4, and the main journals are *Defence Science Journal*-8, Proceedings of ICSCN 2007: International Conference on Signal Processing Communications and Networking-5, Proceedings-1st International Conference on Emerging Trends in Engineering and Technology, ICETET 2008-5, and *Information Technology Journal*-4.

(10) *Classification (89)*

The focus is on classification and feature extraction of sensed and imaged entities. The main institutions are: NIT-11, Coimbatore Inst Tech-5, Anna Univ-5, and the main journals are *International Journal of Remote Sensing*-6 and Proceedings-International Conference on Computational Intelligence and Multimedia Applications, ICCIMA 2007-5.

(11) *Pattern Recognition (50)*

The focus is on pattern recognition, especially face recognition, handwriting recognition, and optical character recognition. The main institutions are Jadavpur Univ-5, University of Mysore- 5, IIT-Madras-3, Vishwakarma Institute of Technology-3, and the main journals are *Pattern Recognition*-5, Proceedings-International Conference on Computational Intelligence and Multimedia Applications, ICCIMA 2007-3, Proceedings-1st International Conference on Emerging Trends in Engineering and Technology, ICETET 2008-3, and Lecture Notes in Computer Science (including subseries lecture notes in Artificial Intelligence and Lecture Notes in Bioinformatics)-3.

(12) *Imaging/Remote Sensing (89)*

The focus is on imaging/remote sensing, with emphasis on SAR, ground penetrating radars, and thermal imaging, and interest in textures, land coverage, and target identification.

The main institutions are IIT-Roorkee-10, DRDO-Elec/Comp Sci-9, ISRO-7, NIT-5, Indian Stat Inst-4, and the main journals are Proceedings-International Conference on Computational Intelligence and Multimedia Applications, ICCIMA 2007-9, *Defence Science Journal*-8, Proceedings of SPIE-The International Society for Optical Engineering-7, and *International Journal of Remote Sensing*-6.

Some further insights can be derived from the above clusters (research domains). Some of these can broadly be matched to the 20 thrust areas identified by DRDO[1] (refer for thrust area; section 'Defence Research Infrastructure').

Two clusters, namely, chemical agents and energetic materials are primarily addressed by DRDO. This would imply that these research areas are highly specific to military; these can be classified as military- identifiable according to the terminology.

Two clusters are primarily addressed by IITs: heat transfer (GaN devices), and optimal control/particle swarm/ ANN. This shows the core competency of IITs in areas that have strong relevance for military research.

Four clusters can be identified wherein universities, engineering schools, and research laboratories are active. These clusters are: sensors/routing protocols (MEMS); intrusion detection (active protection system); classification (stealth); and pattern recognition. In these areas, it can be said that the research requires interdisciplinary focus.

Four clusters can be identified that show involvement of different institution types: universities, engineering schools, research laboratories, and DRDO. These four clusters are: fluid dynamics/computational fluid dynamics (aerodynamics); structural/strength of materials/ballistics (functional materials); target tracking/Kalman filter (active protection system); and imaging/remote sensing (active protection system).

The broad identification of clusters with institution types and matching of the clusters with DRDO thrust areas shows the varied linkages in the development of military research capability, and also shows which of the thrust areas are producing outcomes in terms of open literature research papers.

7. CONCLUSIONS

The methodology for identifying military relevant literature appears to provide credible results. The volume of literature retrieved will vary by how strongly relevant is the desired literature. For the same definitions of 'military-relevant', India's literature in the *Ei Compendex* was an order of magnitude less than that of the USA or China.

The role of information technology in strongly military-relevant technology has increased to the point where it has surpassed the more traditional physical and engineering science and technology components associated with military-relevance. The leading performers in the information technology component of the strongly military-relevant technologies are the universities and institutes of technology (and ISRO), while the leading performers in the physical and engineering science and technology components are the DRDO laboratories, along with some of the institutes of technology.

It is to be explored whether the DRDO laboratories-IITs collaborations are integrated to their fullest extent. Extramural funding by DRDO to IITs exhibit one dimension of collaboration; this is more in the sense of one-way knowledge transfer. To investigate two-way knowledge exchange, some collaboration spot checks were performing in the *SCI* database (basic and applied research), where collaborations would be at the basic research level and would be expected to be higher than collaborations at the advanced technology development level. The fraction of DRDO laboratories' total publications which are co-authored with one or more IITs ranged from ~30 per cent (Defence Metallurgical Research Laboratory) to 0 per cent (High Energy Materials Research Laboratory) or 1 per cent (Defence R&D Establishment), with more being on the low side. It is recommended that an examination of all the R&D outputs of the DRDO laboratories be done to ascertain the levels of collaboration with other institutions, especially educational institutions, and whether these actual collaboration levels are near the optimal desired.

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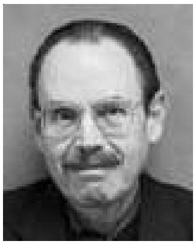
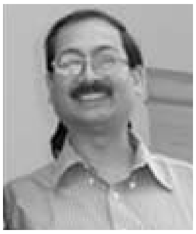
Contributors



Dr Ronald Neil Kostoff obtained his PhD (Aerospace and Mechanical Sciences) from Princeton University in 1967. He worked, at Bell Labs on technical and economic studies; at US Department of Energy managing energy programs; at US Office of Naval Research (ONR) managing and evaluating research programs; and at MITRE Corporation, where he continues, on text mining work. His orbiting molecular shield (aka wake shield) invention pioneered the capability of high vacuum in low orbit, presently exploited by all manned space vehicles. His initial aero-braking research pioneered the aero-assisted orbit transfer sub-field of orbital transfer vehicles.



Dr Sujit Bhattacharya obtained his MSc (Physics) from Delhi University, and PhD (Informetrics) from Indian Institute of Technology, Delhi. Presently, he is working as Scientist at National Institute of Science Technology and Development Studies, CSIR, Delhi. He was Visiting Professor at the Centre for Studies in Science Policy, Jawaharlal Nehru University, Delhi. His main area of research work is in science and technology policy studies covering S&T indicators, innovation studies, and intellectual property rights. He has published over 40 research papers in peer reviewed journals and conference proceedings. He has co-authored two books and has been co-editor.

The views in this document are solely those of the authors, and do not necessarily represent the views of The MITRE Corporation or the National Institute of Science, Technology and Development Studies or the Jawaharlal Nehru University. The first author's contribution was supported by MITRE internal research.