Defence Science and Technology Organisation (DSTO) Submission to the Australian Academy of Science "Decadal Plan for the Mathematical Sciences 2015-2025"

Mathematics in DSTO

DSTO's purpose is to be a national leader in safeguarding Australia by delivering valued scientific advice and innovative technology solutions for Defence and national security. We are predominantly an applied research organisation, with a small but important component addressing basic research and looking at the longer time horizons. We can therefore offer a view of both the current and future demands for mathematical sciences, particularly from a Defence perspective.

The breadth of applications of mathematics over the past 100 years for Defence science has been profound. Mathematical skills are essential for DSTO to be able to deliver its outcomes for Defence; there would scarcely be a domain of application in which mathematical sciences is not present to some degree. As at 23 April 2013, the DSTO science and technology workforce consisted of approximately 18% staff employed in the mathematical sciences. The DSTO workforce also consists of staff employed in the Engineering & Systems Sciences, Physical Sciences, Information, Computing and Communication Sciences, Human, Social and Health Sciences and in S&T Management. The non-mathematical science work areas all rely on under-pinning mathematics and statistics to a greater or lesser extent.

In addition to this under-pinning breadth of application of mathematical sciences, there are some specialist areas of endeavour where DSTO has contributed to the development of high-end mathematical science itself, such as cryptography, autonomous systems, signal processing, control theory and others.

Over the next five years DSTO's priority themes include: cyber, space and surveillance systems and autonomous systems, as well as sustaining its investment in electronic warfare, information systems and chemical, biological, radiological and nuclear science and technology areas. Other capability areas of importance include propulsion and energy, platforms, weapons, human sciences and operations analysis. Overall, we expect to see an increase in the importance of mathematical sciences to the work of DSTO into the future. Cutting-edge mathematics is anticipated to underpin many of the emerging technologies for effective cyber capabilities, control of unmanned platforms, satellite guided weapon systems, smart sensors, bioinformatics, and advanced control and communications in military operations.

DSTO takes the view that mathematical sciences is a foundational capability for the organisation, essential both to deliver our current program and also to provide the generic skills and capabilities to take us into a changing future.

In summary DSTO strongly supports the ongoing development of mathematical sciences in Australia and welcomes the mathematical sciences community's initiative in developing a Decadal Plan. DSTO is especially keen to see the plan deliver improved mathematical and statistical outcomes which can be applied across the broader science, engineering and technology domains.

Current Demand

At DSTO, there are a number of mathematical science disciplines currently in demand. The most important competencies are (not in priority order)[1]:

1. Pure mathematics
    - Algebra and number theory
    - Combinatorics and discrete mathematics
    - Real and complex functions
    - Mathematics associated with Information and Computing Sciences
    - Mathematical Physics
2. Applied mathematics
    - Operations Research including both deterministic and Probabilistic OR
    - Biological mathematics
    - Applications of control theory to engineering
3. Numerical and Computational Mathematics
    - Numerical analysis
    - Optimisation
    - Applied statistics
    - Biostatistics
    - Stochastic Analysis and modelling
4. Computation theory and Mathematics
    - Analysis of algorithms and complexity
    - Applied discrete mathematics
    - Computational logic and formal languages
    - Mathematical software
    - Numerical computation

These mathematical science competencies are then applied across a broad range of application areas, including planning deployment and scenario evaluations for campaign plans, predicting spread of chemical and biological agents, control and communications, advanced signal processing, design of advanced armour and platforms, satellite guided weapon systems, and large-scale computational codes in the design of platforms, simulation of weapons and trajectories, and the training of personnel.

Future Demand

While the current demand will continue, we see future demand in application areas covering ever more complex, capable and distributed systems, and those which could herald a step-change in capability such as quantum information science. Notable problem domains requiring mathematical skills include:

1. Mining large datasets
2. Quantum Information theory

[1] The select list of competencies is based on the ARC classification scheme for Maths.

3. Computer Sciences
    - theoretical computer sciences
    - algorithm and problem analysis
    - algorithm complexity and efficiency
    - distributed computing
    - artificial intelligence algorithms
4. Automation and machine learning
5. Advanced Signal Processing
    - Discrete event systems
    - Data fusion
    - Control theory
    - Information Theory
    - Random process
    - Stochastic processes
    - Tracking and sensors
    - Multi-static and multi-user systems
6. Inverse problems

The Mathematical Skills Pipeline

DSTO has a keen interest in the maintenance of strong mathematical sciences in schools and universities. DSTO favours an approach that recognises that STEM starts in schools and develops students in advanced mathematics through secondary school years leading to tertiary qualifications that includes modern scientific programming languages and experimental mathematics. For its part, DSTO is in the process of establishing a Maths Forum @ Schools program and cadetships initially to be offered to women and indigenous persons but later to be extended more broadly. Over the next 5 years, DSTO also proposes to increase the proportion of staff with PhDs, professional and technical qualifications including broader industry and/ or academia experience. This would include those with qualifications in the mathematical sciences.

DSTO's primary desire is that the mathematical sciences pipeline delivers sound mathematical skills to students in all the STEM disciplines and beyond. Turning to graduates in the mathematical sciences themselves, DSTO's principal requirement is that they are able to apply their mathematical skills to real world problems and the domain they work in, such as signal processing, cryptology or social network analysis. Mathematics graduates would therefore ideally have had a broad education with an ability to understand and appreciate an issue from various points of view. They would have an appreciation of real-life issues, possibly work experience in the work place and can understand and think through the implication of their decisions. There would be increased emphasis on the use of computers in mathematical teaching and students would have been exposed to the philosophical and historical understanding of scientific and mathematical thinking.

Key attributes that DSTO is seeking from mathematical science graduates are:

1. **High quality Australian mathematicians**. Much of DSTO's work is security classified, which requires us to employ either Australian nationals or people who have become Australian citizens. The security clearance process is most straightforward when we are able to employ people who have come through the Australian education system. Possible areas to consider:
    a. National curriculum model from kindergarten to year 12
    b. Specialist maths teachers in Primary schools.
    c. Seek to reduce decline of staff numbers in University Maths departments.
2. **Advanced mathematics skills**. DSTO has areas of application of mathematical sciences which are at the leading edge of capability. We are finding the supply of highly talented mathematicians is becoming increasingly problematic. Possible areas to consider:
    a. A decadal plan from primary school through secondary school to university education that encourages the take-up of advanced mathematical subjects, for both boys and girls.
    b. Encourage schools to have students participate in the Australian Mathematics Competitions, and such enrichment as participation in the Maths Olympiad.
3. **Problem solving**. As a predominantly applied research organisation, DSTO is in the business of using science and technology to develop solutions to complex and difficult problems. Practical approaches to problem solving complement a mathematician's theoretical understanding, such as for the notion of Nondeterministic Polynomial time (NP)-complete/hard problems. Possible areas to consider:
    a. Encourage greater emphasis on problem solving skills, such as Polya's "how to solve it" supplementing deductive reasoning teachings.
4. **Working in teams**. The majority of DSTO's programs require multi-disciplinary teams working together (to solve complex and difficult problems). DSTO values staff who have deep expertise in their own right, but also have the skills and attributes which enable them to work in teams. Possible areas to consider:
    a. Encourage team-based approaches to solving complex problems, in both schools and university curricula.
5. **Integration of maths, statistics and research design**. A specific example of multi-disciplinarity is the integral role of mathematics and statistics in the design, and subsequent analysis, of research experiments and trials. Possible areas to consider:
    a. Encourage the linking of maths and statistics in a more integrated way.
    b. Encourage the linking of mathematics to engineering and other physical sciences.

A completed pro-forma is attached to this submission at **Annex A**.

Annex A
to DSTO's Submission

(Optional pro-forma for)
Submission to the Australian Academy of Science
"Decadal Plan for the Mathematical Sciences 2015 - 2025"

Introduction

The Australian Academy of Science, through the National Committee for Mathematical Sciences (NCMS), is overseeing the development of the first Decadal Plan for the Mathematical Sciences, covering the period 2015-2025. The Academy is working closely with the Australian Mathematical Sciences Institute and the discipline's societies and associations in the development of the decadal plan.

The plan will be comprehensive in scope, ranging from training and education at school level through to research in specialised centres and an international perspective. There are groups charged with looking at the future of the Mathematical Sciences in government agencies, and in business and industry.

The Mathematical Sciences consists primarily of the disciplines of Mathematics, and Statistics. Data from the ABS Census 2011 records shows that there 21,847 people reported their highest post-school qualification was mathematics, and 4,616 people reported statistics. 13,436 of these people worked in the private sector, and a further 3,491 in national government. From a government agency perspective this definition may be too restrictive, and we invite you to include issues affecting the other numerate professions employed in your agency when formulating your thoughts, especially with regard to the 'education and training in schools and colleges' strand of the plan.

The development of the plan is in its early stages, and submissions made now will be able to influence the shape and direction of the plan as it develops. Views from government agencies and business and industry will be particularly valuable. Although that is where the significant majority of mathematical science professionals work, by and large they are dispersed across many locations and organisations and fill many roles, and the issues and future needs from their perspectives, and those of their employers are less well understood at present.

More information about the plan can be found at the website, http://www.mathscidecadalplan.org.au, which is also where submissions can be lodged.

Context about your agency

Agency Name : Defence Science and Technology Organisation

Is your agency :

✓	A line department ?
☐	A statutory authority ?
☐	Other ? Group within Department of Defence

Is your agency part of :

✓	The Australian Government?
☐	A State or Territory Government?
☐	Other ? Please describe.

Is your agency primarily engaged in :

☐	Policy development / research ?
☐	Program delivery ?
☐	Both policy and program delivery ?
✓	Other? Predominantly research and program delivery (to Defence) with a smaller component in policy development

Please indicate the approximate number of employees in your agency

☐<100	☐ 101 to <500	☐ 501 to<1000	✓ 1001to<2500	☐ 2501 to <5000	☐ 5000+

Please briefly describe the work of the agency

DSTO is a national leader in safeguarding Australia by delivering valued scientific advice and innovative technology solutions for Defence and national security.

Data analysis and mathematical modelling (at the agency)

Please describe briefly the roles that data and analysis play in the work of the agency

As a science R&D agency, mathematics is the common language in which much of the agency's research in specialist fields is conducted and reported. Moreover quantitative data analyses are expected to underpin any recommendations DSTO puts forward to Defence. Therefore we expect the majority of staff to have good quantitative analysis skills regardless of their primary discipline, that they will exercise these skills regularly, and that they are quite likely to have to expand them in the course of research on new problems.

Examples where data analysis and mathematical modelling play a significant role in DSTO's work include big data mining; operations research and operations analysis; human sciences including cognitive analysis; sensitivity analysis; algorithm and problem analysis, and modelling to understand the threat from potential bioterrorist attacks and naturally occurring pandemics.

Please rate the importance of mathematical modelling and data analysis to the following aspects of the work of the agency.

Activity	Importance of mathematical modelling and data analysis to the activity				
Policy development ☐Not applicable	☐ Irrelevant	☐ Low importance	☐ Moderately important	✓ Quite important	☐ Essential
Program delivery ☐Not applicable	☐ Irrelevant	☐ Low importance	☐ Moderately important	☐ Quite important	✓ Essential
Other Scientific Research and Technology design.	☐ Irrelevant	☐ Low importance	☐ Moderately important	☐ Quite important	✓ Essential

Any other comments about the use and importance of data analysis and mathematical modelling by the agency

As noted above, as an employer of graduates across the science, technology, engineering and mathematics stream DSTO sees data analysis, mathematical modelling and similar quantitative activities more as integral components of its overall R&D activities rather than separate discrete activities carried out by specialist staff.

In effect, DSTO conducts research across the full range of mathematical sciences because of their practical applications.

As an employer DSTO is in need of a sustained pool of good/high quality Australian (sovereign / local) mathematicians noting that individuals would be required to work in a highly classified environment.

Statisticians, mathematicians and related professionals at the agency

Please provide a brief description of the types of roles that statisticians, mathematicians, and related numerate professionals fill in the agency. Examples of typical job titles would be particularly helpful to us at this stage of the development of the plan.

In delivering valued scientific advice and innovative technology solutions for Defence and national security DSTO employs approximately 2000 people with a science and technology qualification. DSTO expects most of its staff to have some level of mathematical skills, it also expects some of its staff to have sufficiently deep skills to be able to advise and educate the rest when these reach the limits of their expertise, and in some cases to do original mathematical research.

As at 23 April 2013, DSTO science and technology workforce consisted of approximately 18% staff employed in the mathematical sciences. More broadly, DSTO staff are graduates of or work in the Engineering & Systems Sciences, Physical Sciences, Information, Cryptology, Computing and Communication Sciences, Human, Social and Health Sciences and science and technology Management. All these disciplines rely on or make use of mathematics, many rely heavily on mathematics.

Typical job titles include Research Scientist, Senior Research Scientist, Research Leader, Scientific Advisor, and Chief of Division. Typical roles in the mathematical sciences include analytical specialist, numeric simulation and modelling specialist, operations research specialist, mathematician, and statisticians at various levels.

Please provide the following information, where applicable / available, about the people in professional (numerate) roles in the agency.

Role / job titles	Approximate number employed	Typical salary range	Comments
Research Scientist	107	96,000 – 108,000	In mathematical sciences
Senior Research Scientist	164	111,000 – 151,000	In mathematical sciences
Research Leader	7	160,000 – 175,000	In mathematical sciences
Please enter role here.	Approximate number.	Typical salary range.	Any other comments.
Please enter role here.	Approximate number.	Typical salary range.	Any other comments.

Does the agency recruit or employ individuals with formal mathematical science (or related numerate discipline qualifications) in generalist or policy roles (as opposed to specialised professional mathematical science roles)?

✓ Yes
☐No

If yes, approximately how many employees in generalist roles are known to have mathematical science or related professional training?

Although the formal mathematical science in generalist or policy roles is not a pre-requisite an unspecified number of employees have a mathematical background especially in finance roles.

If yes, how useful is the mathematical sciences or related professional training regarded in respect of their work in the generalist role?

☐ Irrelevant	☐ Only occasionally useful	☐ Moderately useful	✓ Regarded as an asset in most circumstances	☐ Used frequently and highly regarded

Compared to other positions in the agency, how difficult is it considered to be to recruit people with mathematical science or related professional qualifications for:

Specialist / Professional roles	☐ Much easier	☐ Easier	☐ About the same difficulty	✓ More difficult	☐ Very difficult
Generalist roles	☐ Much easier	☐ Easier	✓ About the same difficulty	☐ More difficult	☐ Very difficult

Are there any other comments about the recruitment, employment, roles and suitability of training of employees with mathematical science or related professional qualifications?

When it comes to recruitment and mathematics, the key concern for DSTO is ensuring all recruits have the mathematical training needed to perform effectively in their discipline. What DSTO wants from the education system (and university mathematicians in particular) is effective delivery of advanced mathematical education to students in all departments, not just mathematics. This is particularly important when it comes to undertaking advanced research in many fields important to defence such as radar or optics: advances in these areas are almost always framed in mathematical terms and often require quite advanced mathematics.

DSTO's expectations of mathematical sciences graduates are that they have a broad education, which has exposed the graduate to range of issues and topics. Graduates would have an appreciation of real-life issues, ideally have some experience in the work place, and the ability to understand and think through the implication of their decisions. They should have the ability not just to do mathematics but also to communicate it: they should be able to explain the reasoning behind their results to others, and to spread around the skills and techniques they used to reach these results so that others can produce similar results in future. Finally they should have a philosophical and historical understanding of scientific and mathematical thinking.

- Problem solving skills
- Mathematical analysis
- Statistical and random process
- Numerical analysis and programming

Themes proposed as relevant to government agencies

The group looking at the future of the mathematical sciences from the perspective of government agencies has identified 5 broad themes that require further consideration.

Details can be found on the Decadal Plan website (http://www.mathscidecadalplan.org.au). The themes identified by the 6 other groups (covering topics ranging from education in schools and colleges through to an international perspective) are also available from the website.

In brief the themes considered most directly relevant to government agencies are:

1. Supply : Ensuring the future supply of appropriately skilled staff (this also falls in the scope of the groups looking at education and training in schools, and education and training in universities)
2. Value : Describing the current and future contribution that the mathematical sciences can or should make to achieving the goals of public service agencies (both in the operations of the agency, and in the delivery of the services and programs for which the agency is responsible)
3. Career options : Describing the breadth and variety of the careers available in the Public Service for people with a mathematical science or related qualifications, and considering issues which might influence the attractiveness of such careers to future graduates
4. Environment : Creating the right environment for the mathematical sciences to contribute to agencies' goals, with emphasis on :
    a. Leadership (by the mathematical science professionals themselves, and from senior management with respect to the use of the professional mathematical science skills)
    b. Information (with a focus on seeking to ensure that the collection, management and availability of information is designed into agency operations and service delivery programs so that the professionals have the raw materials of their trade)
5. Professional community : (and linkages between the mathematical sciences and the other professions employed in agencies, and between the mathematical science qualified employees and their professional colleagues in other agencies, overseas, and in academia).

How important does to the agency consider addressing these themes to be in the development of a successful 10 year plan for the Mathematical Sciences?

Ensuring supply	☐ Not very important	☐ Mildly important	☐ Of some importance	☐ Quite important	✓ Very important
Establishing value	☐ Not very important	☐ Mildly important	☐ Of some importance	☐ Quite important	✓ Very important
Attractiveness of career options	☐ Not very important	☐ Mildly important	✓ Of some importance	☐ Quite important	☐ Very important
Creating the right environment	☐ Not very important	✓ Mildly important	☐ Of some importance	☐ Quite important	☐ Very important
Professional community and linkages	☐ Not very important	☐ Mildly important	☐ Of some importance	✓ Quite important	☐ Very important

Do you have any comments about these 5 themes?

Enter comments about ensuring the supply of professional staff for the agency

While we have been successful in recent years in recruiting mathematically-sophisticated staff, we have found staff outside these specialist areas lack mathematical depth. Moreover, due to the classified nature of work there are difficulties in ensuring a continuous supply of Australian mathematics graduates.

Enter comments about the value of the mathematical sciences to the agency

Mathematical science is recognised to be central to the delivery of a significant proportion of our output, both as an under-pinning discipline across a range of application areas and as discipline in its own right for applications where high-end mathematical science skills are required.

Enter comments about the attractiveness of professional careers in the agency

While only a handful of careers in DSTO are strictly mathematical, the organisation has a demand for mathematicians who are willing to apply their skills to specific problems and domains. What the organisation offers are a broad range of problems that are sufficiently important and substantial as to generate plenty of motivation, as well as the necessary resources to solve such problems. Our approach of seeking “the best implementation of the best algorithms on the best hardware” combines elements of pure and applied mathematics at basic and advanced levels.

Enter comments about creating the right environment for the professionals to contribute to the agency

As an applied research agency, DSTO aims to create a stimulating and supportive environment for multi-disciplinary, team-based programs of work addressing problems of national importance. Given the recognition in both DSTO and Defence of the value of mathematical sciences and their existing integration with other disciplines, DSTO has not needed to establish any additional specific mechanisms for mathematicians per se.

Enter comments about the merits of enhancing linkages amongst members of the mathematical science community in the Public Service and with other professions employed in the Public Service

There are a number of strong reasons for maintaining linkages between an organisation such as DSTO and the broader professional mathematical community, in particular

- Researchers in many fields, not just mathematicians, need ongoing exposure to or training in the latest mathematical and statistical techniques for application in their problem domain
- Those involved in teaching mathematics need to keep up with the ever changing demand for particular areas of mathematics
- The mathematics community needs the greater weight that wider research organisations can lend to particular fields and research programs through sponsorship of conferences, research contracts, collection of data or provision of research infrastructure

Are there any other issues or themes the agency considers should be addressed in the Decadal Plan, for it to be useful for government agencies?

See main body of submission

Looking ahead

Over the period from now until 2025 does the agency believe that the relevance of the mathematical sciences to the work of the agency will become:

☐ far less important than now	☐ less important than now	☐ remain the same as at present	✓ more important than now	☐ much more important than now

Any further comments about expected future changes to the usefulness of the mathematical sciences to the work of the agency?

DSTO's long standing demand for experience and skills in mathematics will only grow given DSTO's increased strategic focus in such science and technology capability areas as cyber, space and surveillance systems, autonomous systems, advanced signal processing, bio-simulation, E-health data mining and epidemic modelling to name a few. Cutting-edge mathematics is anticipated to underpin many of the emerging technologies for effective cyber capabilities, control of unmanned platforms, satellite guided weapon systems, smart sensors, bioinformatics and advanced control and communications in military operations.

We are hoping to compile some case studies illustrating the types of contribution the mathematical sciences / mathematical science professionals can make to achieving the goals of government agencies

Are you able to provide any specific examples where valuable contributions have been made (or even have failed to have been made):

Insert brief outline of example contribution here

- Bio-preparedness Corporate Enabling Research Program - To understand the threat of potential bioterrorist attacks, as well as naturally occurring pandemics, models are developed of how infection is introduced into a community, how it develops and manifests itself in individuals, and how this may lead to observable electronic health signatures. These models help inform development of data fusion algorithms to mine e-health databases.
- Operational reach-back for first responders- Short turn-around atmospheric hazard prediction models are required in emergency situations that deployed Australians have faced, including advice to Operational planners for military campaigns, as well as large scale disasters (e.g. Fukushima). Hazard modelling capability has also been established for large events, e.g. Olympic Games, CHOGM.
- Chemical, biological and radiological laboratories generate data, as do human performance laboratories facilities, and ballistics and materials laboratories. Extensive outreach to large databases is also routinely undertaken. Extensive field trials generate data on equipment performance and human performance. A broad range of physics-based modelling is undertaken in the areas such as human physical performance, aerosol transport and deposition, radiation propagation, intra-cellular toxin transport, and disease transmission. Without a sound mathematical science foundation running across all these activities, a coherent research program could not be delivered.
- Mathematical modelling and optimisation of sensors, weapons, platforms, and operations are key to DSTO's ability to provide sound advice to Defence.

Further contact?

Who should we contact if we desire further information or clarification?

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Contacts phone number. 6128 6246

We may wish to quote parts of the reply in the report and the final plan. Do we have your permission to quote parts of this submission and attribute them to the agency?

☐ Yes	✓ Please contact the agency to seek clearance about specific quotes and attributions	☐ Material may only be used in general quotes, anonymously	☐ No