NRC·CNRC Office of Audit and Evaluation

Evaluation of NRC's Digital Technologies Research Centre

Final Report

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National Research Council Canada
Conseil national de recherches Canada

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Acknowledgement

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Acronyms and Abbreviations

AEP	Advanced Electronics and Photonics
ASJC	All Science Journal Classification
CAS	Courts Administration Service
CS	Computer Systems Administrator
CWI	Canadian Wheat Improvement
DARPA	Defence Department's Advanced Research Projects Agency
DG	Director General
DT	Digital Technologies
EBP	Employee Benefit Plan
FTE	Full Time Equivalent
FWCI	Field-Weighted Citation Impact
FY	Fiscal Year
GDP	Gross Domestic Product
HCI	Human-Computer Interaction
HHT	Human Health Therapeutics
HPB	High Performance Buildings
ICT	Information and Communication Technologies
IP	Intellectual Property
IRAP	Industrial Research Assistance Program
IT	Information Technology
KITS	Knowledge and Information Technology Services
LPSS	Learning and Performance Support Systems
MAT	Multimedia Analytic Tools
MATS	Multimedia Analytic Tools for Security
MRAP	Management Response and Action Plan
NGO	Non-Government Organizations
NRC	National Research Council
OAE	Office of Audit and Evaluation
OGD	Other Government Department
OTS	Other Technical Services
PIP	Performance Information Profile
PRC	Peer Review Committee
R&D	Research and Development
RCO	Research Council Officers
RO	Research Officers
SSC	Shared Services Canada
TBS	Treasury Board of Canada Secretariat
TO	Technical Officer
TRL	Technology Readiness Level
WHO	World Health Organization

Executive Summary

In 2017-2018, an evaluation of the National Research Council's (NRC) Digital Technologies (DT) Research Centre was conducted. The evaluation covered the period from fiscal year 2012-13 to 2016-17 inclusive. The evaluation was led by an independent evaluation team from NRC's Office of Audit and Evaluation in accordance with the NRC's approved evaluation plan and the Treasury Board of Canada Secretariat (TBS) policies. The Research Centre and its programs had not been previously evaluated.

The evaluation assessed the performance, capacity and relevance of DT and its two programs: Multimedia Analytic Tools for Security (MATS) and Learning and Performance Support Systems (LPSS).

Summary of Key Findings

The DT Research Centre comprises world-class researchers across a number of areas. DT personnel have made substantial research contributions and impacts to the field of digital technologies, including highly-cited publications and technology used across many domains (e.g., applying machine translation to indigenous language education and to global health). DT's broad engagement with industry, other government departments, and other NRC research centres also delivers consulting services and knowledge transfer for the betterment of Canada.

Although DT has achieved some success, significant recent changes in structure and leadership have hampered its ability to develop a clear vision and strategy. DT also faces challenges with talent attraction and retention and is understaffed to meet the forecasted needs from within the NRC and beyond. In addition to human resources, DT does not currently have adequate infrastructure to respond to future needs and remain competitive in the field. Specific key findings for each area examined in the evaluation are highlighted below.

Performance

DT is in high demand and is valued by internal and external clients. MATS projects have led to improved productivity and enhanced security for clients, while capability projects have contributed to national and international advancements. Despite increases in skills and knowledge, some clients highlighted the need for post-service maintenance of products.

Capabilities and Expertise

The capabilities and scientific excellence of DT scientists are well recognized, particularly in the areas of machine translation, sentiment analysis, and computer vision and graphics. DT's renowned expertise is evidenced by leadership in top international conferences and journals, adjunct professorships, international awards, and high impact publications. However, DT has recently lost a number of staff. DT is competing with careers in the private sector and with academia, which may be more attractive than the NRC (e.g., salary, benefits, access to high caliber facilities and equipment). Challenges surrounding talent retention may impact the current state of DT expertise.

Continued Need

The field of digital technologies is extremely relevant within NRC, nationally and internationally. Given this increase in need in the field, DT has the opportunity to make significant impacts across a broad spectrum of clients and partners. DT, however, is not currently well positioned to respond to future needs based on the existing human resources and computing infrastructure. Furthermore, DT's limited access to compute power, storage facilities and software tools and platforms will limit DT's ability to stay competitive in the field, collaborate with other organizations, and recruit and retain talented staff.

Recommendations

The evaluation findings have led to three recommendations in the areas of strategic planning, human resources, and infrastructure.

1. **DT should develop a comprehensive strategic research plan.** The DT Research Centre should focus on continuing its efforts to secure a permanent, indeterminate Director General. The plan, led by the new DG, should clarify the mission and vision of the research centre, consider how researchers can focus on research projects with relief from external engagements, and include an engagement strategy.

2. **Given that expertise in digital technologies is in high demand (i.e., the talent pool is small), and research in this area evolves rapidly (i.e., areas of high demand can quickly become stale), DT should ensure stability of staff by leading the development of a formal human resources plan focusing on talent acquisition and retention of staff.** The plan should consider the new strategic direction of the research centre, attracting graduate and postdoctoral students to enhance capabilities and revitalize all locations of DT, and strategies to hire for the long term, with consideration of diversity.

3. **The DT Research Centre should ensure that researchers have timely and controlled access to needed digital research infrastructure, including both hardware (compute and storage) and software.** Actions should consider approaches to work in partnership with new Collaboration Centres to access digital research infrastructure in conjunction with university partners.

1. Introduction

This report presents the findings of the evaluation of the National Research Council's (NRC) Digital Technologies (DT) Research Centre. The DT Research Centre was selected for an evaluation based on consultations with NRC senior management and the work was carried out in accordance with NRC's five-year evaluation plan.

The DT Research Centre had not been previously evaluated. The evaluation covers the period from fiscal year 2012-13 to 2016-17 and addresses three questions:

1. To what extent is the DT Research Centre's research expertise contributing to the achievement of outcomes for both internal and external clients?
2. To what extent has the DT Research Centre developed capacity and expertise in relevant digital technologies-related fields?
3. To what extent is the DT Research Centre positioned to respond to future needs for digital technologies research expertise (NRC and beyond)?

The evaluation was led by an independent evaluation team from NRC's Office of Audit and Evaluation, with data analysis support provided by a consultant. The methodology included multiple lines of evidence (i.e., document and data review, key informant interviews, peer review). A more detailed description of the methodology and its limitations is provided in Appendix A.

This evaluation report is organized as follows:

- Section 2 provides a profile of the DT Research Centre and its programs
- Section 3 presents the evaluation study's findings
- Section 4 provides the conclusions and recommendations
- Section 5 includes the Management Response and Action Plan (MRAP) to the evaluation's recommendations

2. Profile

During the course of the evaluation, the Information and Communication Technologies (ICT) Portfolio underwent a transformation which led to the creation of the DT Research Centre. A brief overview of the transformation of ICT and the establishment of DT is provided below. For a more detailed profile of DT, see Appendix B.

Created in 2012, the ICT Portfolio supported the Canadian ICT industry by de-risking, developing and supporting the commercialization of technologies that met the needs of the ICT industry. To fulfill its mandate, the portfolio operated four programs:

- Advanced Photonic Components
- Printable Electronics
- Learning and Performance Support Systems (LPSS)
- Multimedia Analytic Tools for Security (MATS)

In October 2017, the ICT Portfolio was divided into two research centres operating under the Emerging Technologies Division: Advanced Electronics and Photonics (AEP) Research Centre and the DT Research Centre. The Advanced Photonic Components and Printable Electronics programs were assigned to the AEP Research Centre and the DT Research Centre inherited MATS. The LPSS program was discontinued.

Under ICT, there were eight teams supporting MATS and LPSS. Following the transformation, these eight teams comprised the new DT Research Centre. Teams, based on areas of specialization, include:

- Text Analytics
- Multilingual Text Processing
- Computer Vision and Graphics
- Software Development
- Human Computer Interaction
- Data Analytics
- Data Science for Complex Systems
- Scientific Data Mining

3. Findings

3.1 Performance

DT is in high demand and appears to be significantly valued by internal and external clients. Capability projects have contributed to national and international advancements. While projects increased client knowledge and de-risked early stage of research and development, some challenges were identified, such as the provision of post-service maintenance.

The performance of the DT Research Centre and its programs was examined by assessing activities, outputs, and intended results with the intent to answer the following evaluation question: To what extent is the DT Research Centre's research expertise contributing to the achievement of outcomes for both internal and external clients?

Achievements – Capability Projects

One of DT's major capability projects is in the area of machine translation.[1] Key clients pursued work with DT as a result of the international recognition gained by its Machine Translation team. As found in the evaluation of the NRC's initiative under the Roadmap for Canada's Official Languages, NRC successfully deployed Portage to key public sector organizations and one of Canada's largest private sector translation players. For statistical machine translation systems, Portage has been identified as being among the best in the world. It is recognized as state-of-the-art, gaining international recognition as a result of achievements in the United States'

[1] As part of the Government of Canada's Roadmap for Canada's Official Languages (2013-18), the DT Research Centre received funding of $10M over five years to conduct R&D in the area of statistical machine translation and text analytics. A calibrated evaluation conducted by the NRC's Office of Audit and Evaluation was carried out for those projects in 2016 (see https://www.nrc-cnrc.gc.ca/eng/about/planning_reporting/evaluation/2016_2017/initiative_roadmap_official_languages.html; retrieved Apr. 10, 2018)

National Institute of Standards and Technology competitions. DT has also received invitations to participate in prestigious projects funded by the United States Defence Department's Advanced Research Projects Agency (DARPA).[2]

Examples of the impact of Portage on clients are provided below.

- One of Canada's largest translation firms has been using Portage since 2006 and, according to an internal study, it is estimated that Portage has led to improving the productivity of 75 translators by 15 to 20%. Without Portage, this is the equivalent of hiring 11 additional translators.
- In a small independent study, student translators were able to translate an additional 100 words per hour using Portage, for an efficiency gain of approximately 40%. Portage was found to be more helpful for students than experts. According to the study, the minimum daily production target for translators is 1200 words. With Portage, the students produced twice that rate.
- In addition, an internal study conducted by the Courts Administration Service (CAS) concluded that a result of using Portage, CAS was able to increase its productivity by 40%. Internal estimates project $2.4 million return on investment over five years from the $0.2 million CAS spent on its contract with DT.

The Peer Review Committee (PRC) recognized DT's machine translation achievements, as well as its accomplishments in the areas of sentiment analysis and computer vision and graphics. Some examples of those achievements are noted below.

- Natural language: a project which produced many research and commercial licenses, extensive datasets, and classifiers serving as a base to other research. DT has collected multiple first-place rankings in text analysis research challenges such as i2b2 Natural Languages Processing for Clinical Data and the Sentiment Analysis track of SemEval (see Table 5 for highly cited DT publications with examples of natural language work).
- Image analytics: one project resulted in a wide range of technology used for MATS and NRC's Advanced Manufacturing program. It included sensor characterization and simulation, high precision 3D, imagine processing, and remote 3D shape detection.
- Information extraction: one project produced several important algorithms and tools, including specialized web scrapers, specialized entity extraction tools, relation recognition and time canonicalization models.
- Data analysis for public health crises: a project which delivered technologies and models, including seasonal expectation compensation, interval-based aberration detection, and decision tree differential syndrome definition.

Achievement of Research Centre-Level Outcomes

DT's capability projects, along with MATS and LPSS projects and support to other NRC research centres, enabled DT to achieve the outcomes that follow.

Increasing knowledge and technical skills

Some internal and external clients have limited knowledge of digital technologies and therefore benefited from working with DT staff on their projects. Interviewees noted that their companies were able to pursue additional work, develop additional tools or incorporate new techniques

[2] NRC Information and Communications Technologies. *Machine translation: benefits and advantages of statistical machine translation and NRC's Portage.* National Research Council Canada, April 2015.

because of the knowledge and skills they gained or enhanced as a result of working with DT staff. Some interviewees noted that DT staff were 'very patient' and able to simplify deliverables so that they could understand the science behind their projects. One project made a considerable impact internationally and the client confirmed that this was made possible entirely from the knowledge they gained by working with NRC.

While MATS projects generated high praise from clients, a few LPSS projects were less successful, particularly with respect to increasing knowledge or technical skills. Although these clients reported that DT staff were extremely knowledgeable, some clients reported wanting more face-time, expressing that the relationship was not collaborative enough.

Within other NRC research centres, all interviewees confirmed that their projects with DT led to increases in knowledge (e.g., through co-publications). DT staff also provided examples of knowledge transfer, including one data analytics project for which DT built predictive algorithms for the client's platform that led to two international innovation awards as a result of working with NRC (i.e., Retail CIO Outlook's list of "Top 10 Retail POS Solution Providers 2016" and Supply & Demand Chain Executive 2016 "Pros to Know" awards).

De-risking early stage Research and Development (R&D)

Many external clients reported that DT contributed to de-risking early stage research and development, and most of these clients felt that the outcome had been achieved. Clients did not always have the capacity or expertise to do the R&D on their own, and DT was engaged with testing and problem solving. For example, one client confirmed that their organization now has a product that works well and that risks were reduced as a result of working with NRC.

DT staff also provided examples of projects which contributed to de-risking. Staff reported developing demonstrations for clients, prototypes, and proof of concepts. Examples include:

- Target selection in biologics: DT developed an extensive data warehouse with over 10K gene data samples and protein data to improve searches and optimize targets for treatment and specific applications in biologics.
- Proof of concepts on adaptive learning: DT used virtual reality and augmented reality to demonstrate functionalities and possibilities for (a) developing new training simulations and the future training agenda, (b) how to optimize training facilities, and (c) prototypes to guide the acquisition of learning technologies.

Success in advancing technologies to higher Technology Readiness Level (TRL)

Some external clients confirmed that DT did help advance technologies to a higher TRL. In addition, a few noted that although not the intent of the project, some of their work might end up advancing to a higher TRL given the promising approach developed with DT. One client confirmed that licencing had been secured and that NRC will continue to support their project for a few more years for continuous improvement. DT staff also described projects contributing to the advancement of TRL with, for example, the development of interactive software tools (e.g., for prediction or personalization) and the development of new digital platforms.

Technology transfer

DT management reported that the research centre's technology transfer and licensing has been weak. A few internal interviewees also reported that NRC has moved away from licencing products over the past few years. In some cases for DT, the transfer of technology takes place during the design phase (e.g., algorithms), and not at the end product level. Still, some external clients did confirm technology transfer or licencing, and a few additional clients reported that opportunities exist for licensing or new technologies as a result of their projects with DT. For example, one interviewee stated that further collaboration with NRC was envisaged once their system is commercialized, and another interviewee is considering expanding the client base for their product with NRC's collaboration. Finally, one of DT's internal clients from another NRC research centre reported that DT supported a technical project for their external client, which led to the enhancement of the client's product.

With respect to intellectual property and licences, the NRC owns 10 active patents for 5 inventions that fall within the scope of MATS and LPSS. The NRC also signed more than 10 licence agreements with Canadian and international firms, the Translation Bureau, universities, and a local government (Table 1). Although the details and value of the agreements are not available, statistical machine translation systems is a key expertise licenced by DT.

Table 1. DT projects generated patents and license agreements (2013-14 to 2017-18)

Description	MATS	LPSS	Out of Scope*	Total
Unique Patent Applications	3	0	1	4
Total Patent Applications	**5**	**0**	**4**	**9**
Unique Patents Issued	8	0	2	10
Total Patents Issued	**14**	**0**	**2**	**16**
License agreements entered**	-	-	-	12

Notes. Data as of October 2017. All active patents issued relate to specified program area, but the applications were filed prior to the launch of DT's current programs.
*Where application areas fall outside of DT's current programs.
**Data is aggregated and not categorized by program area.
Source: Administrative data

Key DT Patents

2013: Statistical machine translation adapted to context
2013: Deconvolution-based structured light system with geometrically plausible regularization
2013: Text categorization based on co-classification learning from multilingual corpora
2014: Means and a method for training a statistical machine translation system utilizing a posterior probability in an N-best translation list
2014: High resolution high contrast edge projection

Other outcomes/impacts

Some clients representing other government departments confirmed that working with NRC was "the best of both worlds" since NRC provides better services than other government partners and is better than industry/corporations because they are focused on "getting things right".

NRC's national and international recognition was noted to benefit clients, leading to even stronger impacts in the field than anticipated. As noted by the PRC, DT contributions such as applying machine translation technology to indigenous language education and to global health, have had far-reaching effects. As a result of this broad recognition, DT client's reported that the support they received from NRC was perceived positively by others in the field. One client gave credit to NRC's world-class researchers in being instrumental to his product winning international competitions and securing additional contracts.

Finally, one interviewee specifically attributed increased organizational effectiveness to their work with DT, such that the toolsets developed as part of their project led to staff working more effectively.

Challenges

Although expected outcomes were achieved by most projects, some were less successful. Some of the barriers identified below can be linked to program design and issues related to the complex (e.g., very technical) field of digital technologies. For example:

- Some clients desired a stronger, more collaborative partnership with NRC. One client admitted that there could have been better integration between the NRC and their organization to adjust activities/outputs during the course of the project. Another client felt that outcomes could have been stronger with more DT involvement at project inception (i.e., to design the project given his team's lack of understanding of the field).
- Some interviewees from other NRC research centres expressed the importance of having continuity of resources (e.g., the same person/group of people) due to the learning curve for building a particular expertise. For external clients, although DT reported that their programs are not designed to offer post-service maintenance, some reported challenges when attempting to implement projects once their contract with DT ended, despite an increase in their knowledge/skills. One external client attributed an unsuccessful project with DT to staff turnover and the fact that the NRC was unable to find someone who could successfully complete a key portion of the project. The PRC recognized these challenges and identified an opportunity for DT to place more value on in-kind contributions, to better enable knowledge and technology transfer to clients and partners. The PRC suggested that tutorials could be provided along with more traditional services.
- Administrative processes were mentioned by some clients to have caused project delays; two interviewees brought up invoicing issues specifically.

Achievement of Outcomes – Other NRC Programs

Many of the internal staff interviewed from other NRC programs described DT staff as integral to their success, noting that their projects would not have succeeded without them. Most interviewees believed that their projects were either made possible or enhanced as a result of DT's contributions. The PRC also acknowledged the importance of DT's work with other research centres, noting that DT is making a clear contribution to the outcomes across the NRC, supporting over 10 different programs beyond MATS and LPSS. According to the PRC, this is a strong contribution that could even be greater given the increasing role that digital technologies play in all areas of research today.

Table 2 provides examples of how DT contributed to outcomes of other NRC programs, as provided through interviews with other research centres' staff.

Table 2. DT support to other NRC programs resulted in increased knowledge and research outcomes

NRC Research Centre	NRC Program	Purpose of DT Involvement	Outcome(s)
Human Health Therapeutics (HHT)	Biologics and Biomanufacturing	The Biologics program had an interest in cancer proteins; they understood the biology but required additional knowledge and expertise for analysis. DT brought bioinformatics and data expertise to the Biologics Program's biological expertise.	DT supported their research outcomes by building a database (which holds samples for normal tissues and cancerous ones) and performing complex analyses and scientific data mining (for example, DT compiled public data and normalizes it so it can be compared to itself). Co-publications have resulted from their contributions.
Aquatic and Crop Resource Development	Canadian Wheat Improvement (CWI)	The CWI program required scientific data mining expertise to analyse metabolite data versus DNA.	DT supported projects as part of the wheat improvement flagship (plant genomics datasets, sequencing data sets). Research outcomes included new knowledge, exploratory research, publications, and the potential for intellectual property.
Energy, Mining and Environment	Energy Storage	The Energy Storage program required data analytics expertise to support the Canadian Energy Storage Roadmap, a project funded by Natural Resources Canada.	DT led a main pillar of the project as the complex methodology required data analytics expertise. The Roadmap – which will serve as the roadmap for energy storage in Canada – would not have succeeded without DT support. The Roadmap is about to be finalized for Alberta.
Construction	High Performance Buildings (HPB)	The HPB program required data analytics expertise to support HPB on two externally funded projects (a 1 year and a 4 year project).	DT had a higher level of data analytics expertise to enable the HPB program to do more with better efficiency (quicker turnaround). In addition, DT contributions led to publications for both projects and an improved product for HPB's external client.

Source: NRC Research Centre staff key informant interview data

3.2 Capacity and Expertise

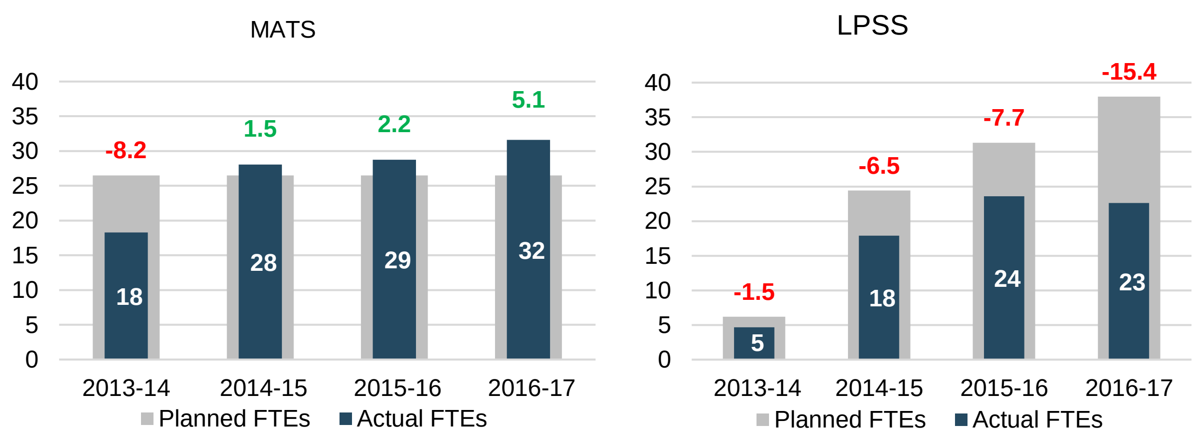
The capabilities and scientific excellence of DT scientists are well recognized, particularly in the areas of machine translation, sentiment analysis and computer vision and graphics. DT's renowned expertise is evidenced by leadership in top international conferences and journals, adjunct professorships, international awards, and high impact publications. However, challenges surrounding talent retention may impact DT's current suite of expertise.

The capacity, capabilities and expertise of the DT Research Centre were assessed by examining existing human resources within the research centre, the demand for DT expertise across NRC, and evidence of scientific excellence and impact. The assessment focussed on the following question: To what extent has the DT Research Centre developed capacity and expertise in relevant digital technologies-related fields?

Capacity

NRC uses a matrix model to manage and allocate its human resources. Although program managers identified resource requirements in the MATS and LPSS business plans, those resources fluctuated over the years (Figure 1). Internal key informants reported that the NRC reliance on revenue in 2015 and 2016 had an impact on staff allocation. Given that LPSS projects generated less revenue than MATS, decisions were made to add more resources to support MATS projects.

Figure 1. Human resources plans were met for MATS, but not for LPSS (2013-14 to 2016-17)

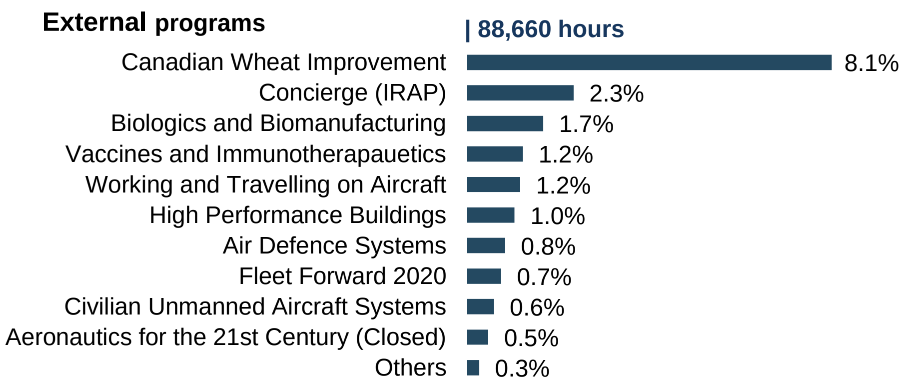


Source: Planned figures: MATS Business plans, July 2013 and LPSS Business plan, October 2013. Actual Figures: Actual FTEs: FTEs based on estimates of 1,450 hours.

Between 2014-15 and 2016-17, DT provided support to nearly all of the NRC research centres. During this time, ICT was ranked second overall among NRC research centres in terms of the percentage of labour it contributed to other research centres, largely due to DT.[3]

Figure 2 shows that DT has supported over 10 different NRC programs beyond MATS and LPSS. Most of this external support was allocated to the Canadian Wheat Improvement (CWI) flagship program and the Concierge program implemented by NRC's Industrial Research Assistance Program (IRAP).

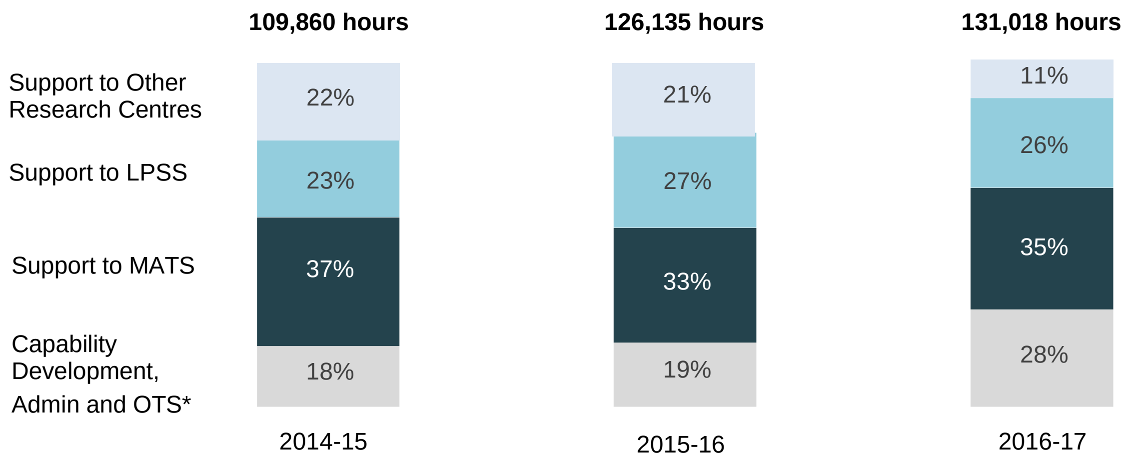
Figure 2. The majority of DT external support went to the Canadian Wheat Improvement program (2013-14 to 2016-17)



Source: Administrative data

DT support to other research centres decreased from 22% in 2013-14 to 11% in 2016-17 (Figure 3). This reduction can be largely explained by the completion of work with the Concierge (IRAP) and the decrease in support to the CWI flagship program. Data also suggest a shift towards more hours being spent on capability development activities.

Figure 3. DT support to other NRC research centres decreased in 2016-17



*Other technical support
Source: Administrative data

3 Labour totalled $7.1 million. Source: NRC SAP data.

Table 3 illustrates how the DT teams differentially support MATS and LPSS. This support has remained relatively stable between 2014-15 and 2016-17. The core teams which support MATS (Text Analytics, Multilingual Text Processing, and Computer Vision and Graphics) and LPSS (Human Computer Interaction, Software Development, and Data Analytics) are highly dedicated to supporting DT projects.

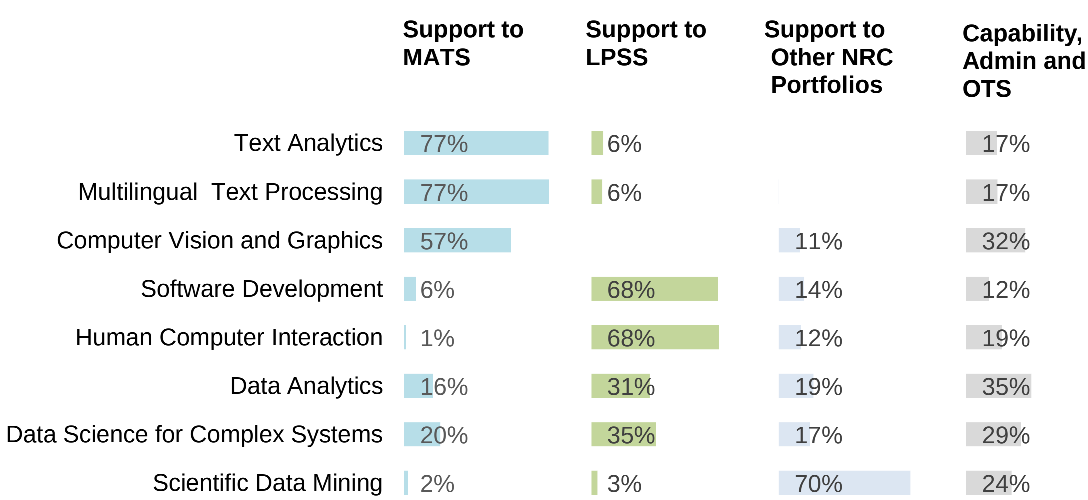
Table 3. MATS and LPSS projects were mostly supported by three teams each (2014-15 to 2016-17)

DT Teams	MATS (% hours)	LPSS (% hours)
Text Analytics	36%	4%
Multilingual Text Processing	31%	3%
Computer Vision and Graphics	23%	0%
Software Development	3%	40%
Human Computer Interaction	0%	34%
Data Analytics*	4%	12%
Data Science for Complex Systems	2%	6%
Scientific Data Mining	1%	2%
Total	100%	100%

*Data Analytics was a new group created in 2016-2017.
Source: Administrative data

Figure 4 shows that the Scientific Data Mining team is the only DT team which primarily supports other NRC research centres.

Figure 4. Core MATS and LPSS teams are highly dedicated to supporting DT projects (2014-15 to 2016-17)



Source: Administrative data

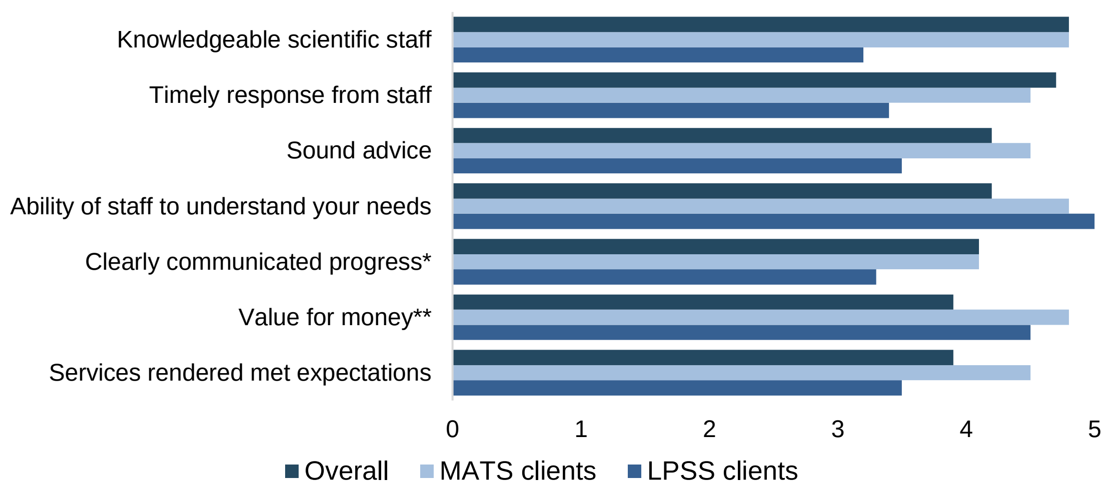
Capabilities

DT staff have capabilities which are well aligned with the current field of digital technologies. The PRC noted that, based on resumes, DT personnel bring a range of expertise of varying strengths and have some world-class researchers – many who hold leadership roles in top international conferences and journals, and who are adjunct professors in university and co-supervise students.

Between 2013 and 2016, nearly half (43%) of DT research staff were PhD researchers, including Research Council Officers (RCO), Research Officers (RO), Technical Officers (TO), and Computer Systems (CS) groups. This is higher than the average for all NRC research centres of 39% for the same period. Further, a large proportion of DT staff are trained in computer science (58%) and engineering (15%). Another 19% of staff were educated in other science disciplines and 9% had obtained degrees in social sciences. Finally, more than half (63%) of DT staff are research personnel (i.e., RO/RCO), while 35% are Application Developers (i.e., CS). Technical officers account for 2% of research personnel.

External clients were asked about the capabilities of the DT staff they worked with on projects. MATS and LPSS clients rated their experiences working with DT across a number of quality measures. As illustrated in Figure 5, most of the measures generated positive ratings, with knowledgeable staff ranking highest.[4]

Figure 5. External clients were very satisfied with DT staff



Note. Satisfaction scale: Not at all satisfied (0) to Very satisfied (5). *On reports and results. **Price reflected versus value received. Source: External Clients Key Informant data.

External key informants also expressed that DT: (a) has staff who are specialists with a broad range of expertise, allowing for greater flexibility; (b) uses novel approaches; (c) was one of the best groups doing work in automated machine translation; (d) has a Computer Vision and Graphics group that is recognized as one of the best in the world.

[4] The ratings were broken down by program given the differences between MATS and LPSS ratings. The ratings for LPSS were somewhat lower, in part because LPSS clients did not feel the projects were as collaborative as they would have liked. One of the LPSS projects was terminated after two months due to a lack of perceived leadership and poor project delivery.

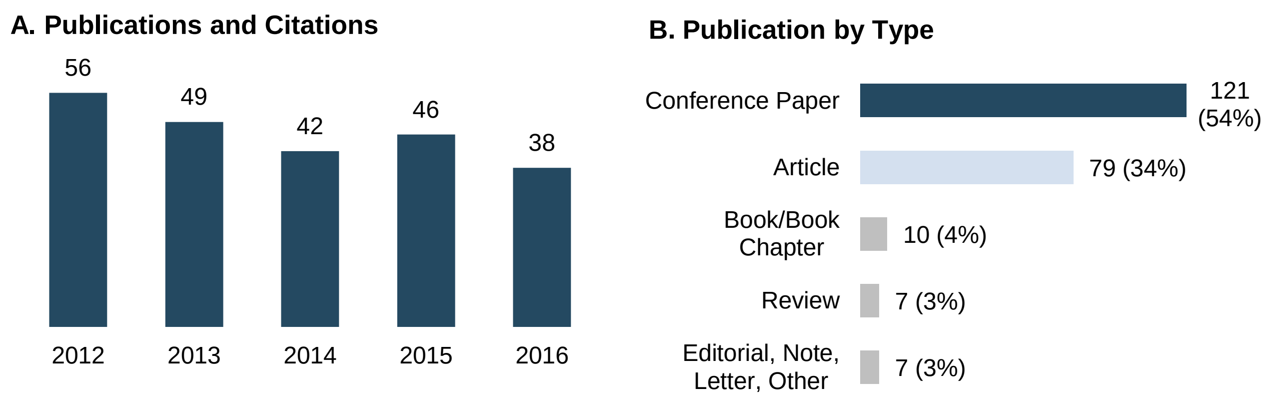
Other research centre interviewees identified clear capability gaps in their research centres that DT was able to fill.

Expertise

Scientific excellence and impact

From 2012 to 2016, the volume of DT researchers' publications indexed in Scopus (224 peer-reviewed publications authored by at least one DT researcher) was relatively stable with an annual average of 45 publications, but slightly decreased by an average of 10% annually (Figure 6). This is consistent with the pattern seen for all NRC publications for the same time period. More than half of DT publications were conference papers (54%). This publication pattern of predominantly conference papers is typical of computer science, and has remained relatively consistent for DT publications in the period studied. According to self-reported publication disclosure for 2016, MATS and LPSS accounted for 70% of the ICT portfolio's conference papers (28% and 11% respectively of ICT's total output).

Figure 6. DT scientific output was relatively stable and consisted predominantly of conference papers (2012-2016)



Source: NRC, Digital Technologies 2012-2016 Publications: A Bibliometric Study, December 15, 2017.

On a national scale, DT researchers were highly collaborative (51%). This collaboration rate is higher than the rest of NRC (32%) and Canada (11.5%) suggesting that DT plays an important role in catalyzing and enhancing the competitiveness of Canadian R&D in the field (Table 4). Top DT collaborators come from universities close to the DT Research Centre's sites.

Table 4. DT national collaborations catalyze the Canadian R&D ecosystem (2012-2016)

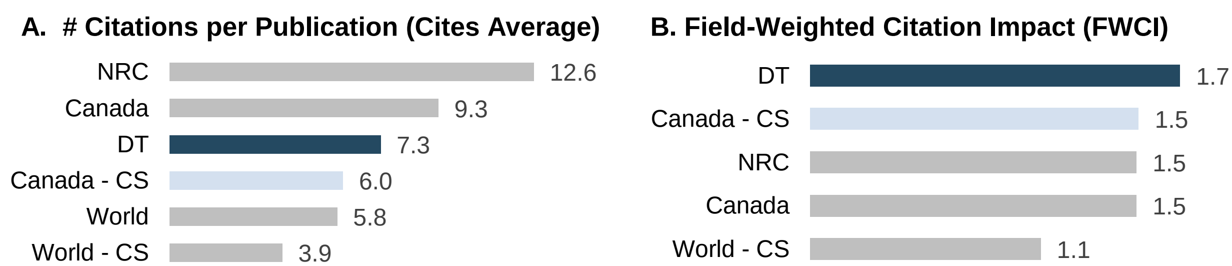
Top Collaborating Countries		**Top Collaborating Organizations**	
Canada (non-NRC)	51%	University of Ottawa	17%
United States	8%	Université de Moncton	8%
China	7%	Carleton University	6%
Germany	5%	Université de Sherbrooke	3%
Japan	4%	Atlantic Cancer Research Institute	2%
Italy	3%	University of Alberta	2%
France	2%	University of British Columbia	2%
United Kingdom	2%	University of Toronto	2%
Belgium	2%	Saarland University, Germany	4%
Saudi Arabia	2%	Nanjing University, China	4%
# Co-Publications	192	# Co-Publications	115

Source: NRC, Digital Technologies 2012-2016 Publications: A Bibliometric Study, December 15, 2017.

In terms of scientific excellence as measured by citation count per publication, the impact of DT publications is comparable to Canadian publications authored in Computer Science. DT researchers' publications had an average of 7.3 citations per publication, somewhat lower than NRC's average of 12.6 citations per publication and the Canadian average of 9.3, but slightly higher than the averages number of citations received by Canadian and World publications in Computer Science (Canada-CS and World-CS) (Figure 7a). The PRC recognized that DT staff are publishing well, given the constraints that they work in when compared to an academic environment.

DT's scientific impact is high in its field, according to the Field-Weighted Citation Impact (FWCI).[5] Publications authored by DT researchers had an overall FWCI score of 1.70 for 2012 to 2016. DT researchers' FWCI score is higher than all other entities used for comparison (Figure 7).

Figure 7. DT researchers' publications were cited 20% more often than the Canadian average (2012-2016)



Source: NRC, Digital Technologies 2012-2016 Publications: A Bibliometric Study, December 15, 2017.

[5] The Field-Weighted Citation Impact (FWCI) is a normalized citation indicator that takes into account the differences in research behavior across disciplines. An overall FWCI score of 1.70 means that DT researchers' publications were cited 70% more often than the world average of 1.0 for publications within the same main subject area, the same document type, and during the same period.

When looking at specific subject areas (using All Science Journal Classification (ASJC) categories) in which DT has more than 20 publications, the scientific impact of DT publications outpaced the FWCI values for Canada (and the World) in Linguistics and Language studies (i.e., text analytics),[6] Computer Applications, and Artificial Intelligence. Ten publications with an average citation count of 77.4 were highlighted as most impactful for DT (Table 5). Most (8/10) publications are authored by current DT researchers, indicating that DT has a strong continuing base of expertise.

Table 5. Top 10 highly cited DT Publications (2015-2016)

Title	Source (Journal or Conference)	Year	# Citations	Source CiteScore (2016)	FWCI	Scopus/ SciVal Views
Crowdsourcing a word-emotion association lexicon	Computational Intelligence	2013	173	2.38	36.18	56
BigBrain: An ultrahigh-resolution 3D human brain model	Science	2013	128	14.39	5.98	90
Sentiment analysis of short informal texts	Journal of Artificial Intelligence Research	2014	127	4.02	15.85	110
Batch tuning strategies for statistical machine translation	Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies	2012	81	n/a	21.13	9
A data-model-fusion prognostic framework for dynamic system state forecasting	Engineering Applications of Artificial Intelligence	2012	71	3.74	5.54	69
Feature selection for high-dimensional class-imbalanced data sets using Support Vector Machines	Information Sciences	2014	53	5.37	7.37	1898
Domain and function: A dual-space model of semantic relations and compositions	Journal of Artificial Intelligence Research	2012	46	4.02	4.49	13
Biomechanically constrained groupwise ultrasound to CT registration of the lumbar spine	Medical Image Analysis	2012	36	3.58	3.58	32
Sentiment, emotion, purpose, and style in electoral tweets	Information Processing and Management	2015	31	2.38	7.51	52
Using hashtags to capture fine emotion categories from tweets	Computational Intelligence	2015	28	2.38	6.85	48

Source: NRC, Digital Technologies 2012-2016 Publications: A Bibliometric Study (December 15, 2017).

[6] Note the similar categories Language and Linguistics (Arts and Humanities) and Linguistics and Language (Social Sciences): these typically apply to articles on text mining and sentiment analysis, but with a slightly different emphasis, depending on the nature of the journal.

Reputation and recognition

The NRC was perceived to have leading experts in fields of digital technologies which are of importance to clients (external and within NRC). Many external clients and some interviewees from other NRC research centres described DT staff as being "brilliant", "renowned" and "respected". One interviewee whose project was not completed as planned noted there were no issues with NRC's scientists – challenges were due to project delivery and not due to lack of skills/capabilities.

External experts and the PRC also recognized DT's achievements and expertise. The PRC noted that DT personnel have been productive both in the projects and in their academic communications. Experts identified Computer Vision and Graphics (e.g., 3D imaging), Text Analytics, Data Analytics, Data for Complex Systems, Sentiment Analysis and Machine Translation as areas which are leading edge.

Contest Winner (2014)
DT scientists Pengcheng Xi and Chang Shu were challenged to recognize the locations of six landmarks on hundreds of 3D human body scans at the Seventh Eurographics Workshop on 3D Object Retrieval (SHREC). Their algorithm of graphic models achieved the highest accuracy in locating three landmarks on test scans and comparable accuracy in locating the other three.

Contest Winner (2015)
The Circular Secondary Structure Uncertainty Plot - Visualizing RNA Secondary Structure with Base Pair Binding. 5th Symposium on Biological Data Visualization, Dublin, Ireland.

i2b2 Challenge Wins: Informatics for Integrating Biology and the Bedside. DT scientists demonstrated information extraction beyond superficial co-occurrence of concepts, with insights on causality and intent.

2010

1st - identifying medical problems, tests, and treatments from patient record narrative
1st - assigning qualifiers to problems (present, absent, possible, etc.)
2nd - typifying the pairwise relations between problems, tests, and treatment

2011

4th - patient-written text used (suicide notes) to annotate sentences with emotion labels

2012

1st - patient record narrative used (relative and simplified time annotations were added to 'Events' in the narrative: Event-A happened [before/overlap/after] Event-B)

Challenges

Capacity concerns

Given the anticipated demand for expertise in digital technologies (internally and externally) and the expected rate of growth, talent acquisition and retention was identified by the PRC to be of significant concern for DT. Overall, DT scientists represent only a small part of digital technology fields and there is some question about the sufficiency of the personnel to cover a broad set of topics requiring varying expertise. Further, the PRC noted that there may also be areas of expertise lacking within DT (e.g., systems, data science, software engineering, statistics, Internet of Things), while other areas may require more depth (i.e., artificial intelligence and machine learning).

One external expert interviewee also questioned how DT scientists were able to keep up with this rapidly changing field given their relatively low staffing complement. The expert was of the opinion that, given the number of DT research areas, the research centre is stretched by trying to work in too many areas, and that focusing on a niche area may be more valuable. This expert noted that academic institutions are better situated to adapt to the pace of digital technologies given stronger post-doctoral streams and the number of researchers. While there was also acknowledgement from the PRC that hiring world-class researchers with expertise in digital technologies is a challenge at NRC, they noted that a strategy and overall vision for DT would help support attraction and retention. The PRC recommended promoting the positive aspects of working at NRC, including good work-life balance, job stability and opportunities for cross collaborations with other research centres. They also suggested a focus on researcher diversity and hiring post-doctoral researchers to keep ideas and research topics fresh.

Finally, DT's reliance on Shared Services Canada (SSC) was identified by the PRC as a significant challenge. SSC's technology-related service support hampers DT's research capacity as a result of the delays with respect to acquiring access to required equipment and/or privileges (e.g., permissions to download necessary development software). Furthermore, the equipment is aging. The field is moving so quickly and becoming, especially in data science, reliant on high-performance and high-volume facilities, that access to such resources is critical. The PRC recommended exploring strategies and mechanisms to enhance existing compute infrastructure through external partnerships.

Capability concerns

The PRC noted that the newly established Data Analytics team had no staff with PhDs and the lowest number of personnel. The work of this team focuses primarily on assisting external clients with data challenges (e.g., data analysis/interpretation), particularly NRC IRAP clients. The PRC believed that industrial work should be better aligned with strategic directions, and that there is an overreliance on DT researchers to support IRAP.

Other concerns

External experts expressed that they were unable to find information on DT scientists or projects on the NRC website. Some DT staff also noted that restrictions in posting on the web resulted in reduced visibility and credibility. In part, these barriers are due to communications requirements within NRC and the Government of Canada.

All of the external experts interviewed noted that for some of the eight DT teams, there appeared to be significant overlap with arbitrary borders between the teams. They mentioned it was difficult to understand how capabilities were organized within NRC. For instance, interviewees often would group Data Analytics with Text Analytics and Scientific Data Mining. One key informant was surprised that artificial intelligence was not reflected more prominently in the DT teams' capabilities' description, but did recognize that DT's machine learning and deep learning capabilities would be capable of addressing artificial intelligence needs given its area of focus.

3.3 Continued Need

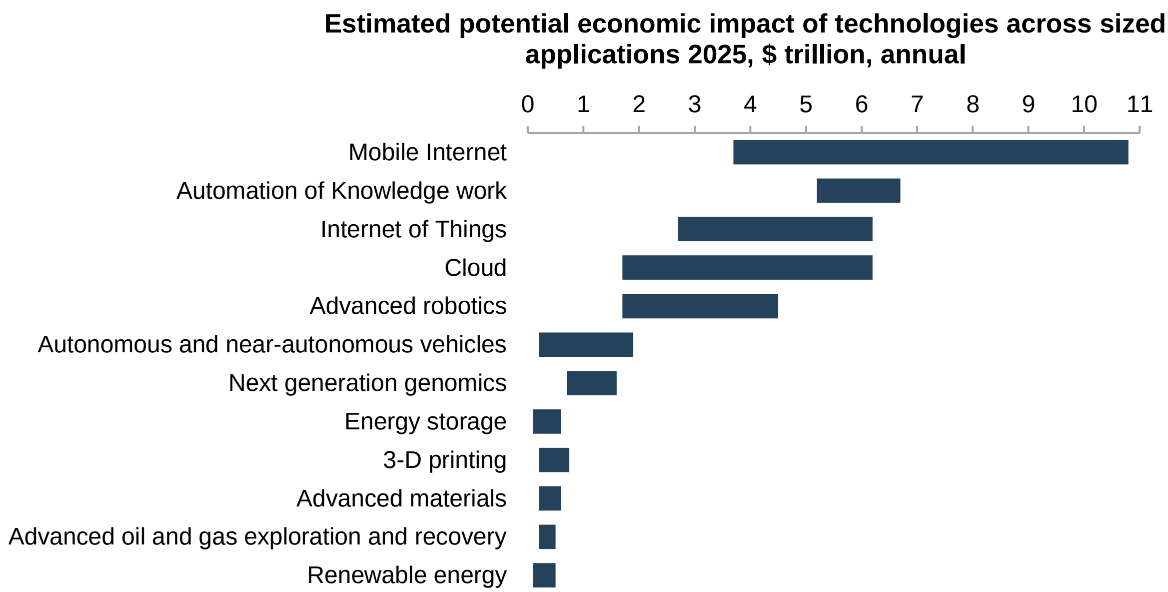
The field of digital technologies is top-of-mind nationally and internationally. Given this increasing interest in the field, DT has the opportunity to make significant impacts across a broad spectrum of clients and partners. While DT has expertise aligned with a range of high-impact technologies which have the potential to improve the health, safety, and productivity of Canadians, DT is not currently well positioned to respond to future needs based on the current state of resources and infrastructure.

The relevance of the DT Research Centre was assessed by examining the current and future needs in the area of digital technologies research, as well as its capacity to meet those upcoming needs. The assessment was carried out to address the following evaluation question: To what extent is the DT Research Centre positioned to respond to future needs for digital technologies research expertise (NRC and beyond)?

Future needs for research expertise in digital technologies

The field of digital technologies continues to be at the forefront of R&D opportunities. In terms of economic impact, the potential of technologies is calculated in the trillions of dollars and is expected to continue to grow[7] (Figure 8). This includes technology needs for which DT is well-positioned to respond, given the experience and expertise within the research centre (e.g., automation of knowledge, internet of things, advanced robotics). This also includes technology needs which have been identified by NRC as important areas of focus.

Figure 8. DT expertise is well aligned with high impact technologies



Source: McKinsey Global Institute

[7] McKinsey Global Institute.

Need – NRC and Government of Canada

Within NRC, recent initiatives demonstrate the need for research in digital technologies. NRC's Dialogue identified increasing research excellence in disruptive technologies and improving the NRC research environment as two out of its four key focus areas. Moving forward, the NRC Action Plan 2017-2021 identifies the future NRC as being a leader in "targeted disruptive technology areas" and delivering "technologies in key innovation clusters".[8] These areas constitute the way forward for all NRC programming, and given the focus on digital technologies research, there appears to be strong alignment with DT activities and expertise. It also confirms the importance of the DT Research Centre's current and future activities across NRC.

As demonstrated by DT's labour contributions to nearly every NRC research centre (see section 3.2, Capacity and Expertise), there is an NRC-wide demand for DT expertise. Many of the NRC staff from other research centres described DT staff as integral to the success of their collaborative projects, with most expressing that their projects were either made possible or enhanced as a result of DT's contributions. A few interviewees also expressed wanting more time with DT, but were restricted due to their own budgetary constraints.[9] DT management noted that the recent "explosion" of interest in digital technologies across Canada has made it applicable to everything else across NRC. There is recognition that across the organization, other research centres are "ramping up" their need for machine learning and Artificial Intelligence and that, consequently, the demand for DT support will increase.

The PRC also acknowledged the need for DT across NRC, noting that DT is clearly important and has the opportunity, given its excellence in personnel and track record of achievement, to make significant impacts across a broad spectrum of clients and partners. To remain relevant moving forward, however, the PRC felt that DT must retain its ability to produce new research in digital technologies, and mobilize and apply new research findings across the NRC. Across the NRC, personnel in other research centres also have capabilities in digital technologies. The PRC felt that DT should provide a concentration of researchers in computer science and closely related areas, and be a nucleus to create and lead communities of practice with other NRC research centres providing access to digital technologies.

The PRC believed that the current areas of focus within DT are appropriate for addressing many pressing problems, recognizing that DT capabilities also align with high impact technologies and upcoming national supercluster initiatives. In fact, three of the five supercluster initiatives rely on digital technologies capabilities (Table 6). Notably, one of the five superclusters is focused specifically on developing a supercluster of digital technologies expertise, in order to apply it to the needs of local enterprises (mining, health, and manufacturing).

[8] NRC Dialogue Implementation. *NRC Action Plan 2017-2021*. August 2017.
[9] NRC Research Centres have fixed staffing envelopes. Other research centres may not have the financial resources to hire DT staff, or, DT may be unable to hire or assign staff to meet the needs of another NRC research centre based on their own budgetary or hiring restrictions (as was noted by one research centre interviewee).

Table 6. Supercluster initiatives are aligned with DT capabilities

Name	Region	Description of Digital Technologies involvement in Funded Supercluster	Planned Economic Impact*
Digital Technology	British Columbia	Projects designed to boost Canada's precision health, manufacturing and resource environment technologies by advancing data collection, analysis and visualizations.	$5B GDP 13,500 jobs
Next Generation Manufacturing (NGN)	Ontario	Projects using big data, intelligent machines and the internet of things to scale and improve production efficiency in different manufacturing industries.	$13.5B GDP 13,500 jobs
SCALE AI	Quebec (Quebec-Windsor Corridor)	Projects focusing on the implementation of AI and data science in supply chains, particularly in the retail, manufacturing and infrastructure sectors.	$16.5B GDP 16,000 jobs

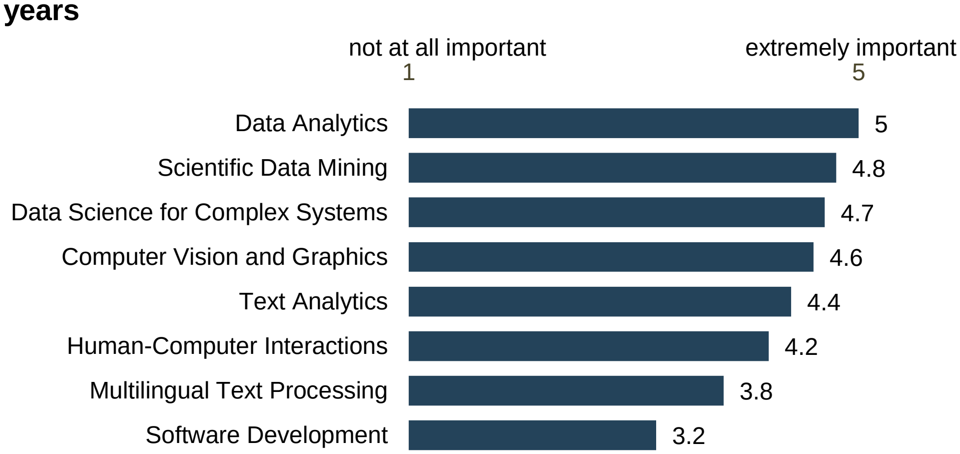
*After 10 years
Sources: Innovation, Science and Economic Development, Innovation Superclusters Initiative webpages; Research Money, Volume 32 Number 2, February 21, 2018.

Need – nationally and internationally

External experts with expertise in the field of digital technologies offered their perspectives on the future directions in the field, and the needs of DT relative to the research centre's current areas of focus. As illustrated in Figure 9, data analytics was rated as the most important area of focus based on existing DT teams – there is tremendous global interest in this area by academia, industry and government alike.

Digital technology trends are at the heart of many new business trends (e.g., mobile internet, Internet of Things, automation of knowledge work). According to interviewed external experts, the DT research areas are very relevant, and some of the work will continue to address needs that cross sectors. Many of the areas have wide applicability. For instance, data analytics can span from health care to national security, neuroscience, finances, and transportation.

Figure 9. Experts agree that most of DT's areas of focus are very important for the next five years



Source: Key informant interviews

Machine learning was noted by two external experts as an area that may require more R&D than others. One expert identified a need in terms of developing new methodologies, tools and approaches. R&D needs may include human to computer interfaces and learning to work with machines, and the question of how this can be done socially and ethically. One external expert saw an opportunity for DT to position itself in this type of research sphere given its expertise. As noted in the evaluation of NRC's initiative under the Roadmap for Canada's Official Languages, the translation industry (i.e., language industry) "is extremely large and growth in the demand for translation services is expected to outstrip supply".[10] It is expected that machine translation will contribute to fill potential gaps. Finally, one interviewee felt that there are future R&D needs with respect to Graphics Processing Units which the expert described as an area one could delve into and be truly innovative.

In terms of industry's future needs, external experts foresee strong opportunities in digital technologies. Three experts specified that machine learning and human-machine interactions were areas of potential interest for industry. Also, artificial intelligence will be of interest to industry (e.g., autonomous vehicles was referenced by three experts). In sum, as one expert noted, needs will continue to grow, and "NRC needs to position how it can serve us in Canada".

Addressing the needs: human resources

Many DT staff interviewees reported that they are managing their workload adequately for the moment. However, most of the DT personnel interviewed, including DT management, indicated that there will not be a critical mass of human resources available to meet NRC's future needs unless additional resources are allocated to the research centre. That could be explained by:

- High demand for expertise in digital technologies creates particular talent attraction and retention challenges for DT. Rising demands for specific expertise reduces the available talent pool. As a result, positions have been difficult to staff and the pace of hiring has been slow, limiting the growth required to match competitors in a field which is accelerating quickly.
- Talent retention has been a challenge given that DT is competing with careers in the private sector and with academia, which may be more attractive than the NRC (e.g., salary, benefits, access to high calibre facilities and equipment).
- DT's satellite offices face challenges due to attrition – staff have left and have not been replaced.

Although human resources data show that the proportion of turnover has been stable between 2014-15 and 2016-17 (8% to 19% per team), departures in 2017-18 were higher than the average, and include permanent and temporary leaves (leave without pay to pursue other employment opportunities, mostly with the private sector or academia).

Overall, the PRC noted that there is currently significant flux within DT and staff appear to be burnt out over the churn and changes in leadership, and resulting research directions over the past few years. The PRC identified a need to bring stability and focus to DT's research leadership, and to develop a strategy and overall vision for DT.

Regarding human resources to support future demands, the PRC feels that DT is currently under-staffed given the explosion of relevance of the Research Centre both within government

[10] See: https://www.nrc-cnrc.gc.ca/eng/about/planning_reporting/evaluation/2016_2017/initiative_roadmap_official_languages.html (retrieved Apr. 10, 2018)

and the private sector. While the areas of current focus for DT are relevant and demand does align with DT expertise, additional individuals will be needed to lead in some areas to provide additional coverage (e.g., security, systems, data science, and Human-Computer Interactions). Furthermore, while superclusters align with DT capabilities, there is also a need to have a plan and mechanisms in place for linking with them formally (e.g., joint projects, secondments).

According to DT management, substantial hiring (both researchers and technicians) at multiple sites (i.e., the DT centers in Ottawa & New Brunswick, DT-related Superclusters, and/or Collaboration Centers) is forecasted for DT. Given the temporary nature of the current leadership (i.e., the current Director General was appointed on an acting basis, and the search for a permanent Director General is ongoing) and the difficulty in integrating such a substantial staff increase, the PRC identified this as a concern. As hiring has long-term impacts, the PRC recommended that room be left in the DT hiring plan for strategic hiring decisions.

Given the rapid evolution of the digital technologies field, it is difficult to forecast the types of skills that will be needed to support upcoming needs. For instance, a highly desired set of skills can go stale quickly in a rapidly changing field. Research Centre strategic documents address mitigating such risk in the future by partnering with external organizations such as universities and other RTOs.

Addressing the needs: facilities and equipment

The recruitment and retention of talented staff will be difficult without adequate facilities and equipment. At present, there are two main DT facilities: Data Analytics Centre, and Imaging and Graphics, which are outlined below.

Table 7. DT Research Centre facilities and equipment are limited

Data Analytics Centre	Imaging and Graphics Facility
Visualization room includes 4 TV screens, tables and chairs Calculation room hosts high performance computers: ✓ 20 MATS machines ✓ 8 deep learning machines ✓ AC machine	✓ Tools that develop prototypes for 3D surface measurement processes, and process and analyze large 3D data streams ✓ Computer infrastructure and software (imaging sensor data processing visualization and data analysis) ✓ Vapor blast machine for imaging target preparation ✓ Laboratory for development of larger scale imaging system ✓ Secret room for military imaging systems
Services: ➢ Data cleaning, integration and management ➢ Exploratory data analysis ➢ Modeling and prediction ➢ Visualization and decision support	Services: ➢ Evaluation of 3D measurement processes ➢ Build "proof of concept" prototypes ➢ Measure small (100 um) to large (1 m) objects. ➢ Dimensional metrology for surface properties. ➢ Vapor blasting for a matte finish on metals
Limitations: ➢ Access to cloud for storage; real-time analytics; client access to data ➢ Half of MATS fleet and deep learning machines need to be updated yearly	Limitations: ➢ No capacity to develop full scale prototypes = limited to proof-of-concept development ➢ Often need to disassemble prototypes due to lack of components for more urgent projects

Sources: DT Program; Key Informant Interviews, NRC website

Table 7 suggests that the DT Research Centre is not well-equipped to meet current needs, and is limited in its potential to meet future needs. The information collected as part of the document review aligns with information collected through key informant interviews. Most internal interviewees agreed that they did not have access to the equipment and tools they needed to meet current and upcoming needs. Access to better computing resources and software were deemed critical to DT staff's work in addition to being a key factor in attracting and retaining top scientists. Many internal interviewees felt they had no ability to control and manage their own research environment (e.g., server infrastructure, downloading software needed for research).

The PRC felt that the lack of controlled and timely access to digital tools and infrastructure was of significant concern, stressing that undertaking world-class research in digital technologies requires appropriate digital research infrastructure including compute power, storage facilities and software tools and platforms. According to an internal document, one of DT's top scientist had resigned due to lost confidence in NRC's ability to sustain its world-class research program in machine translation and related areas of artificial intelligence, describing DT's computing resources as 'insufficient, unreliable, and difficult to access.'

Facilities and equipment challenges were described by some internal interviewees to have worsened following the NRC's cyber intrusion in 2014, which resulted in additional security measures being implemented across the NRC. Equipment issues were then further exacerbated with NRC having to rely on SSC, which is responsible for offering technology-related services to the majority of the Government's departments and agencies. According to interviewees, the delays in getting access to the required equipment and the loss of privileges (e.g., permissions to download software or install programs) hampers research capacity given that delays can go up to many months (e.g., in one case a DT employee waited four weeks for a computer repair), and even years. DT staff and management reported barriers to accessing some needed development software, because the programs were not approved by SSC. Not having the required tools, limits DT's ability to stay competitive in the field and to collaborate with other organizations such as universities.

As reported by many internal staff, there may be a lack of awareness by SSC of the type of research conducted by DT scientists. A representative from SSC interviewed as part of the evaluation agreed that DT experienced challenges but that to some extent, this was the case for all research centres. An interviewee from SSC also noted that delays also resulted when DT was unable to respond to requests from SSC.

Moving Forward

At the time of writing this report, NRC is examining its options for the next phase of DT activities, especially given the closure of LPSS. First, the MATS program will be renamed Multimedia Analytic Tools, with a broader focus, beyond security. As well, there is indication that a new artificial intelligence program would be launched along with new collaborating centres in New Brunswick and Waterloo. DT is also exploring how it can deliver programming to support the Government of Canada's superclusters initiative. Finally, DT has recently received funding for a project on Indigenous Languages as part of the Government of Canada's Aboriginal Languages Initiative.

4. Conclusions and Recommendations

Overall, the DT Research Centre comprises world-class researchers across a number of areas (e.g., fundamental parts of artificial intelligence, such as machine translation, sentiment analysis, and computer vision and graphics) and has made substantial research contributions and impacts to the field of digital technologies. The contributions made by DT researchers include high-impact publications and technology used across many domains, such as in applying machine translation to indigenous language education and to global health. DT's broad engagement with industry, other government departments, and other NRC research centres also provides skills and consulting services for the betterment of Canada.

The DT Research Centre is in high demand and is clearly valued by internal and external clients. Clients internal and external to NRC reported wanting more of DT's time, both during the course of projects, and also for post-service maintenance. Given this increase in interest in the field of digital technologies, DT has the opportunity to make significant impacts across a broad spectrum of clients and partners. To date, DT projects have led to improved productivity and enhanced security for clients, and capability projects have contributed to national and international advancements.

Despite its successes, DT is not currently well positioned to respond to future needs based on the existing state of human resources and digital research infrastructure. There will be continued high demand for expertise in digital technology fields. DT scientists represent only a small part of digital technology fields and there is some question about the sufficiency of the personnel to cover a broad set of topics requiring varying expertise and support. Currently, DT is understaffed and faces challenges with talent acquisition and retention. DT also has limited compute power, storage facilities and software tools and platforms. Finally, reliance on SSC has hindered the abilities of DT researchers to gain timely access to required digital research infrastructure for their projects. Not having the required tools limits DT's ability to stay competitive in the field, attract and retain top scientists, and collaborate with other organizations (e.g., universities).

As evidenced by the recommendations provided in the next section, moving forward, DT will need to clarify the new strategic direction of DT and ensure the stability of personnel. To improve talent attraction and retention, DT should also dedicate more time to research projects and collaborations (e.g., across the NRC), and explore options for timely access to necessary digital research tools and equipment.

Recommendation 1: Strategic Planning

The DT Research Centre should develop a comprehensive strategic research plan.

The DT Research Centre should focus on continuing its efforts to secure a permanent, indeterminate Director General.

The plan, led by the new Director General, should:

- clarify the mission and vision of the research centre along with roles and responsibilities relative to the new strategic direction of DT (e.g., areas related to supercluster engagements, collaboration centres, and challenge programs)
- consider how researchers can focus on research projects with relief from external engagements
- include an engagement strategy relating to projects with government departments, industry partners, and other NRC research centres (i.e., communities of practice and cross-research centre projects)

Recommendation 2: Human Resources

Given that expertise in digital technologies is in high demand (i.e., the talent pool is small), and research in this area evolves rapidly (i.e., areas of high demand can quickly become stale), the DT Research Centre should ensure stability of staff by leading the development of a formal human resources plan focusing on talent acquisition and retention of staff.

The plan should consider:

- the new strategic direction of the research centre
- attracting graduate and postdoctoral students to enhance capabilities and revitalize all locations of DT
- developing strategies to hire for the long term, with consideration of diversity

Recommendation 3: Infrastructure

The DT Research Centre should ensure that researchers have timely and controlled access to needed digital research infrastructure, including both hardware (compute and storage) and software.

Actions should consider approaches to work in partnership with new Collaboration Centres to access digital research infrastructure in conjunction with University partners.

5. Management Response

Recommendation	Response and Planned Action(s)	Proposed Person(s) Responsible	Timelines	Measure(s) of Achievement
1. The DT Research Centre should develop a comprehensive strategic research plan. The DT Research Centre should focus on continuing its efforts to secure a permanent, indeterminate Director General. The plan, led by the new Director General, should: • clarify the mission and vision of the research centre • consider how researchers can focus on research projects • include an engagement strategy	Accepted. Emerging Technology will secure a permanent DG for DT Research Center. DT Research Center will develop a strategic plan, supported by an operating plan which incorporates the recommended elements.	VP Emerging Technology (ET) responsible to secure permanent DG. DG DT (interim and permanent) responsible to develop strategic plan, with support from VP ET and Directors of DT Research Center for continuity.	Permanent DG by March 2019. VP approval of Strategic Plan December 2018.	Permanent DG secured. VP ET approval of Strategic Plan, minutes of quarterly strategic planning meetings.
2. Given that expertise in digital technologies is in high demand (i.e., the talent pool is small), and research in this area evolves rapidly (i.e., areas of high demand can quickly become stale), DT should ensure stability of staff by leading the development of a formal human	Accepted with additional emphasis on staff development. DT will develop a formal human resources plan focusing on talent acquisition, development, and retention of staff. Plan will consider the strategic direction of the research center,	DG of RC with support from Director of Research, HRG, and VP HR.	May 2019	VP ET approval of Human Resources Plan.

resources plan focusing on talent acquisition and retention of staff. The plan should consider: • the new strategic direction of the research centre • attracting graduate and postdoctoral students to enhance capabilities and revitalize all locations of DT • developing strategies to hire for the long term, with consideration of diversity (e.g., create postdoctoral positions for women in DT)	the attraction of graduate and postdoctoral students, and the revitalization of all existing locations and the establishment of new ones. Plan will include strategies for long-term hiring, outside existing competencies with considerations of diversity.			
3. DT should ensure that researchers have timely and controlled access to needed digital research infrastructure, including both hardware (compute and storage) and software. Actions should consider approaches to work in partnership with new Collaboration Centres to access digital research infrastructure in conjunction with University partners.	Accepted. DT will develop a comprehensive research infrastructure plan as part of its strategic planning process. The infrastructure plan will be developed in collaboration with NRC KITS and Security Branch and will consider Collaboration Centres.	DG DT and Director of Research, with support from KITS and Security Branch.	December 2018	VP ET approval of plan.

APPENDIX A Methodology

Scope

The evaluation of the DT Research Centre and its two programs (LPSS and MATS) covered the period from fiscal year 2012-13 to 2016-17 inclusive. The evaluation was carried out in accordance with the NRC's approved evaluation plan and TBS policies. The Research Centre and its programs had not been previously evaluated.

The evaluation questions were developed based on consultations undertaken during the planning phase of the evaluation and a review of key documents. The questions are as follows:

1. To what extent is the DT Research Centre's research expertise contributing to the achievement of outcomes for both internal and external clients?
2. To what extent has the DT Research Centre developed capacity and expertise in relevant digital technologies-related fields?
3. To what extent is the DT Research Centre positioned to respond to future needs for digital technologies research expertise (NRC and beyond)?

Methodology

Data collection for the evaluation was conducted by an independent evaluation team from NRC's Office of Audit and Evaluation, with data analysis support provided by an external consultant. The evaluation employed the following qualitative and quantitative research methods:

- Document review (including program and portfolio plans and strategies, publicly available industry and government reports)
- Analyses of financial, administrative and performance data (portfolio, program and project level financial and administrative data including revenues, expenses, number and type of projects, results of a bibliometric study, HR data)
- Interviews with DT senior management and staff, and external clients, partners and experts selected in consultation with senior management and a review of project data (internal staff/management n=13, external partners/stakeholders n=12, experts n=6)
- Peer Review

Interviews ranged from thirty minutes to two hours in length (group interviews), and were conducted either in-person or by telephone in the preferred official language of the respondent. Interview guides were developed and questions tailored for each key informant group. Interview questions were shared with respondents prior to the interview.

Table 8. Distribution of interviews by category (n=38)

Category	Description	n
Internal stakeholders	DT Program management	4
	DT Program staff	9
	Other internal NRC staff (e.g., staff across NRC Research Centres, KITS)	7
	Internal stakeholders total	**20**
External stakeholders	Program clients	12
	Experts in the field of digital technologies	6
	External stakeholders total	**18**

Data collected as part of the interviews were coded and analyzed using NVivo software. The analysis of informant opinions presented in this report are based on the scale below.

Figure 10. Description of scale for interview analysis

A few	Some	Many	Majority/Most	All
At least 2 respondents but less than 25% of respondents	At least 25% but less than 50% of respondents	At least 50% but less than 75% of respondents	At least 75% but less than 100% of respondents	100% of respondents

Additionally, the interviews asked program clients to rate various aspects of their experience in working with the DT Program using a numerical scale of 1 (not at all satisfied) to 5 (very satisfied). For the purposes of reporting, the mean rating of their responses were calculated.

Peer Review

Data collected by the evaluation team was analyzed and summarized in a report which was provided to the Peer Review Committee (PRC) along with other background information (e.g., DT staff CVs, project summaries). The PRC was comprised of five individuals who possess expertise in the field of digital technologies. A representative from the NRC Office of Audit and Evaluation acted as the Peer Review Coordinator.

Efforts were made to form a balanced committee, taking into consideration sector (academia, government, industry), research areas, diversity (i.e., female representation) and geography.

Peer Review Committee Member Tasks

The peer review process included three components: the review of the background material collected by the evaluation team, participation in a site visit to the NRC, and the production of a peer review report. The total level of effort required by committee members, including the site visit, was approximately 5 days. As part of the Peer Review Committee, members were responsible for:

- reviewing briefing materials and becoming familiar with the research activities and management practices of DT and its programs
- participating in conference calls in advance of the site visit
- attending and actively participating in the peer review process, including the site visit (which occurred from April 26-27, 2017 in Ottawa)
- providing input into the peer review report
- reviewing the draft peer review report and providing written comments

Initial Assessment

Background materials were sent out to peer review committee members for their review prior to the site visit. Peer review committee members were then asked to conduct a preliminary assessment of DT, based on the background materials, using an assessment grid created specifically for the evaluation. The assessment grid contained a series of questions and required members to indicate an overall score, justification for the score and areas to be further explored during the site visit. A teleconference was held to discuss the assessments and identify key areas to pursue in more detail during the site visit.

Site Visit

The peer review process included a 2 day on-site visit to the NRC in Ottawa, Ontario. The visit, occurred on April 26th and 27th and included presentations and discussions on past, current and proposed research activities, and tours of DT facilities.

Finalizing the Committee Report

The draft report was formatted and edited following the site visit and additional background information on the purpose and methodology was added to create a complete draft. A Peer Review report was produced for DT, in addition to the overall evaluation report.

Limitations

The following limitations were identified during the course of the project. Where possible, mitigation strategies were used to minimize their impact, as described below.

- The transformation of ICT during the evaluation made it difficult to analyze data for DT independently of the ICT Portfolio. Where possible, data was examined at the program level, using program level (LPSS and MATS) information to define DT. Strategic Portfolio documents were developed for the ICT Portfolio and did not always report information at the program level. Efforts were made to work with management to conceptualize DT as it existed within ICT during the scope of the evaluation. Draft strategic documents developed for DT were provided to the evaluation team during the reporting phase of the evaluation.
- Only a limited number of external interviews (clients and experts) could be conducted during the timeframe of the project. Efforts were made to triangulate information across several lines of evidence in order to provide summary information to the peer review committee.
- Interviews conducted with other NRC research staff were limited to individuals currently working on projects with DT, and not with programs who were interested in pursuing projects with DT. This limited the perspectives around DT's resource availability to those who had already secured DT support.
- The DT Research Centre did not have a centralized list that tracks its researchers' and research centre's achievements. The evaluation was therefore unable to get a complete list of achievements and awards. Moving forward, the Performance Information Profile (PIP) for the DT Research Centre will include indicators which track DT achievements.

APPENDIX B DT Profile

Overview of DT Programs and Activities

MATS Program objectives and activities

Launched in 2013, the MATS program is an ongoing NRC program that aims to enable Canadian national security agencies and public safety organizations to match their analysis and data surveillance capacity to the exponential growth of digital information, without the need to hire new analysts. By providing expertise in machine learning, natural language processing, analytics, data fusion and human factors, the program aims to develop software-based analytic solutions that can demonstrate significant quantitative improvement in analyst productivity.

The program works with intelligence and security agencies along with industry multi-nationals, commercial off the shelf vendors, systems integrators and smaller niche companies to develop, test and deliver intelligence analytics solutions. MATS develops software algorithms and prototypes that, for example, find relevant data by rapidly filtering and categorizing large volumes of data including multilingual texts, and detect threats by inferring tone, sentiment and intent of human generated data and information.

The MATS program also provides licensing and collaborative R&D (cost-sharing) opportunities, and fee-for-service work (primarily for improvements, customization, testing or integration of technology).[11]

LPSS Program objectives and activities

In October 2017, the LPSS program was discontinued and existing staff were reallocated to support MATS, other DT projects, including capability projects. This decision to terminate LPSS was made by NRC senior management during the transformation of ICT as part of NRC's program renewal process.

The LPSS program, launched in 2014, sought to facilitate the development and integration of a personalized platform technology for training, knowledge and learning management. The program offered expertise in data mining and analytics, decision support systems, human-computer interface usability, learning and collaborative technologies, machine-based learning/reasoning, and natural language processing.

LPSS worked with strategic partners (industry and OGDs) to develop software components for learning and training. The program was developing a learning and performance support infrastructure to host and deliver services that included, for example, learning services and a resource marketplace; automated competency development and recognition algorithms that analyze workflows and job skills and develop training programs to provide employee training.[12]

[11] MATS Business Plan. July 16, 2013.
[12] LPSS Business Plan. October 8, 2013

Capability projects

DT researchers also worked on key capability projects designed to build their tool sets and knowledge base. These projects are ongoing and, in some cases, involved or attracted key clients. More information on capability projects is provided in Section 3.1.1.

Human Resources

Between the 2013-14 and 2016-17 fiscal years[13], the DT Research Centre employed approximately 84 full time equivalent (FTE) employees[14] with an average of approximately 30 FTEs dedicated to MATS and 21 FTEs dedicated for LPSS. The remaining personnel include researchers dedicated to other NRC research centres. DT has resources which are evenly distributed across teams, with an average of 10 to 13 staff per team between 2015-16 to 2016-17.[15] Nearly 75% of employees are working in Ontario at Ottawa facilities and the remaining are in New Brunswick at facilities in Fredericton and Moncton.

Planned versus actual human resources for MATS and LPSS are presented in Table 9. MATS actual human resources were closer to planned when compared to LPSS. See Section 3.2.1 for additional information and context.

Table 9. Fewer FTEs were assigned to LPSS than planned, while MATS FTEs were closer to planned (2013-14 to 2016-17)

Program	FTEs	2013-14	2014-15	2015-16	2016-17
MATS	Planned	26.5	26.5	26.5	26.5
	Actual	18.3	28.0	28.7	31.6
LPSS	Planned	6.2	24.4	31.3	38
	Actual	4.7	17.9	23.6	22.6

Source: Planned: MATS Business plan (July 2013); LPSS Business plan (October 2013); Actual: Administrative data

DT resources support DT Research Centre programs and projects, as well as programs in other NRC research centres. Between 2014 and 2017, DT supported over 10 different NRC programs beyond MATS and LPSS (e.g., Canadian Wheat Improvement, High Performance Buildings, and Fleet Forward 2020). See Section 3.2 for more information on DT support to other NRC programs.

Facilities

The DT Research Centre has three main locations: Ottawa, Ontario; Fredericton and Moncton, New Brunswick.

Ottawa: facilities include the Data Analytics Centre and the Imaging and Graphics Facility. These facilities are mostly geared for the MATS program and contain infrastructure (e.g., high performance computers, hardware, software) to support the engagement of DT clients, build proof of concepts and prototypes for specific applications, and allow for imaging sensor data

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[13] Data throughout the report will be presented in fiscal years (FY): April 1 through March 31 of the following year.
[14] Since the total number of staff fluctuates during the year and over time due to the hiring of students and staff turnover, averages are presented.
[15] Fiscal years 2012-13 and 2013-14 were excluded from FTE calculations because all DT hours and headcounts were only attributed to Computer Vision and Graphics for these years. The Data Analytics team is also excluded from calculations, as it was a new team established in 2016-2017.

processing, visualization and data analysis. Additional information on these facilities can be found in Section 3.3.3.

New Brunswick: up until the termination of LPSS in October 2017, the New Brunswick locations operated three facilities: the e-Citizen laboratory, the Mobile Human-Computer Interaction laboratory, and the Voice-Multimodal laboratory. NRC has not yet determined the future of the New Brunswick facilities.

Financial Resources

Revenues and Expenditures

Between 2012-13 and 2016-17, expenditures associated with MATS and LPSS projects (i.e., salaries and operational expenses) totalled approximately $24.8 million (Tables 10 and 11).[16] As presented below, MATS has exceeded its operational expenses budget for the majority of years, but has also been increasingly successful in generating revenue.

Table 10. MATS planned and actual revenues and expenditures (2013-14 to 2016-17)

MATS	2013-14		2014-15		2015-16		2016-17	
	Planned	Actual	Planned	Actual	Planned	Actual	Planned	Actual
Salaries (incl. EBP*)	$3.20M	$2.30M	$3.27M	$3.74M	$3.33M	$3.33	$3.40M	$3.74M
Operational Expenses	$0.32M	$0.31M	$0.32M	$0.35M	$0.32M	$0.49	$0.32M	$0.56M
Total Program Cost	**$3.52M**	**$2.61M**	**$3.59M**	**$4.09M**	**$3.65M**	**$3.81**	**$3.72M**	**$4.29M**
Total Revenue	$0.80M	$0.71M	$1.45M	$1.02M	$1.98M	$1.94	$2.15M	$2.79M

Table 11. LPSS planned and actual revenues and expenditures (2013-14 to 2016-17)

LPSS	2013-14		2014-15		2015-16		2016-17	
	Planned	Actual	Planned	Actual	Planned	Actual	Planned	Actual
Salaries (incl. EBP*)	$0.71M	$0.59	$2.91M	$2.45M	$3.73	$3.01	$4.59	$2.90
Operational Expenses	$0.03M	$0.03	$0.13M	$0.08	$0.17	$0.23	$0.17	$0.21
Total Program Cost	**$0.74M**	**$0.62**	**$3.04M**	**$2.53**	**$3.40**	**$3.24**	**$4.76**	**$3.11**
Total Revenue	$0.24M	$0.18	$1.35M	$0.12	$1.70	$0.73	$2.25	$0.58

Note. Facilities/equipment costs fall under the Research Centre budget, which was unavailable for DT.
*EBP: employee benefit plan
Source: Planned: MATS Business plan (July 2013); LPSS Business plan (October 2013); Actual: Administrative data

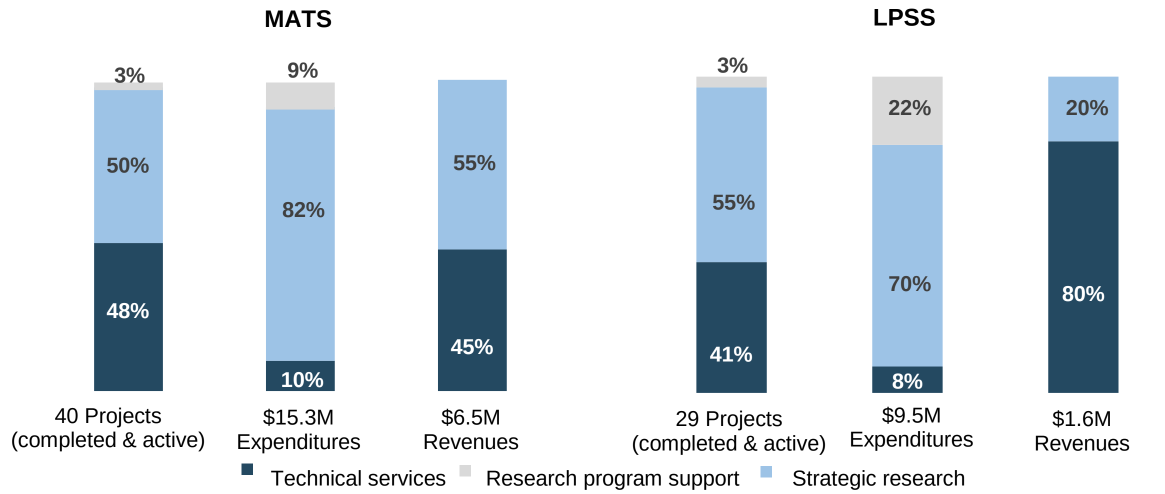
Strategic versus technical service projects

Figure 11 shows that the majority of MATS and LPSS revenues (75%) between 2012-13 and 2016-17 were allocated to strategic research projects (collaborative research projects undertaken with partners to de-risk R&D and accelerate commercial development timelines). Over the same period, MATS generated $6.5 million in revenue, with about half (55%) from strategic research. LPSS revenue totalled $1.6 million, with the majority (80%) coming from

[16] Total DT Research Centre expenditures and revenues were only available for ICT-related activities as the DT Research Centre did not exist until 2017-18. To ensure a better representation of DT, data on financial resources are presented at the program level.

technical service projects (projects that assist clients in solving immediate technical problems through the delivery of specialized fee-for-service support such as testing and prototyping).

Figure 11. While program expenditures are heavily invested in strategic research, significant revenue is generated from technical service projects (2012-13 to 2016-17)



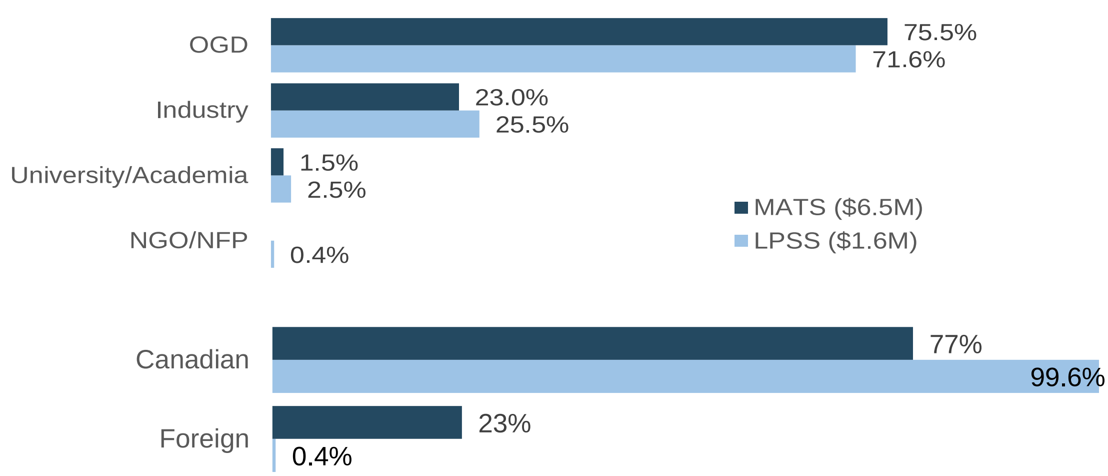
Source: Administrative data

Internal versus external service projects

Over the evaluation period, the majority of MATS projects served OGD clients (75.5%, Figure 12) and revenues for these projects ($6.5M) were consistent with planned revenues. Conversely, LPSS projects primarily addressed internal needs (59%), with the value of external projects being lower ($1.6M) than MATS' revenues.

The DT Research Centre worked with 30 unique clients, with the majority of revenues coming from projects with OGD clients, followed by revenues from projects with industry (Figure 12).

Figure 12. Most of DT revenues come from projects with OGD clients (2014-15 to 2016-17)



NGO: Non-Government Organizations. NFP: Not for Profit Organizations.
Source: Administrative data.

APPENDIX C Achievement of Outcomes

Achievement of Outcomes – MATS, LPSS and Other Research Centres

As part of the evaluation, MATS and LPSS program leads were asked to provide information on outputs produced, and outcomes achieved by projects. Information was analyzed and examples are highlighted below.

MATS client projects[17]

The DT Research Centre worked with a variety of partners and clients. A few examples are highlighted below to showcase the breadth of projects.

- NRC's work helped an agency of the Government of Canada reduce $1 million per year in operational costs by enhancing a high TRL application, part of Canada's contribution to the World Health Organization (WHO). The system is a modernized version of an analytics platform for global health intelligence and is being used by WHO members as an early warning system. On a daily basis, the system analyzes over 20,000 online news reports in nine languages worldwide[18]. The system has been recognized as a Big Data pioneer in public health[19].
- Over a couple of years, DT has been helping a government agency plan for, and develop, a nuclear forensics reference library. The analytical techniques developed were presented internationally, at the request of the client, and continue to gather international interest.
- NRC assisted a client who now maintains a software application and is marketed by a Canadian company. The project solicited interest in Canada and is used by a sister company in Australia as part of intelligence services offerings.
- A key American agency has enhanced secure translation productivity, and further enhanced Canadian R&D competitiveness. Further to that, the project introduced NRC to neural machine translation, which is considered a significant transformation in the field.
- A state-of-the art scraping technology was developed over the course of 2.5 years. The technology is now under licence, and a few key clients have been approached.

Further, advancements in R&D in some MATS projects resulted in improving other MATS projects (capability and client projects). For example, one contract with an international company resulted in new knowledge creation which was then incorporated into *Portage*. Another project with an American agency helped improve capability in one language for *Portage*, and improve the functions and features of another MATS client's project.

[17] Information on projects was sourced from program data files.
[18] Dion M., AbdelMalki P., Mawudeku A., Canada Communicable Disease Report, Big Data and the Global Public Health Intelligence Network, Volume 41-9, September 3, 2015.
[19] PHAC, About GPHIN, https://gphin.canada.ca/cepr/aboutgphin-rmispenbref.jsp?language=en_CA (retrieved March 26, 2018).

LPSS client outcomes

Since its launch in 2014, and until April of 2016, the LPSS program targeted the development of a single platform to serve the needs of end user markets such as oil and gas. However, during 2016-17, LPSS was restructured and a new program lead was appointed. As a result, objectives, plans and priorities were revisited and there was an expansion from security, engineering and machine translation towards natural language processing and analytics for talent management.

The new phase of LPSS sought to develop algorithms to make sense of unstructured and distributed data (and text) for software market segments related to learning, knowledge, skills, talent, and performance management. LPSS projects, designed to personalize and optimize the performance of user systems, fit into four categories: user/usage profiling, competency/skills targeting, competency/skills gap analysis, and filling of competency/skills gaps. Examples of outcomes achieved are presented for each project category.

- User profiling: in 2015-16, LPSS worked with the Treasury Board Secretariat (TBS) to create Micro-Missions, a searchable online bulletin board for Government of Canada employees interested in short-term job interchanges (e.g., short term assignments, job shadowing). The project targeted the development of software tools for TBS to enable the matching of short term work tasks with available personnel within various government departments. It led to great visibility within TBS and led to a series of contracts with the client for enhancing many elements of their GCTools suite of applications.
- Skills targeting: LPSS's platform product called "Jobsee" was an algorithm used to recommend jobs. This LPSS technology – analytics driven by social networks and simple feedback – targeted potential NRC clients and NRC research teams in 2016-17. It was built for showcasing NRC capability to better sell technologies and capabilities of NRC research to external clients. It also served as a target for technology oriented LPSS research: technologies were required to be integrated and demonstrated within the showcase site in order to make them valuable for potential clients.[20]
- Skills gap analysis: In 2015-16, LPSS worked on the first of several successive projects with the Royal Canadian Navy to work on the development of leading edge simulations and other immersive technologies. This work advanced LPSS capabilities in virtual reality technologies and Human-Computer Interactions related to learning applications.

Program-specific challenges

For MATS, according to program documents, there were a few challenges in terms of availability of staff to work on capability projects, which led to project delays.

Challenges for LPSS included lack of appropriate talent within NRC to meet program needs; lack of program and project management support (to ensure the efficiency of project execution within LPSS); and lack of timely support from the Government of Canada's Shared Services Canada (SSC) and NRC's Knowledge, Information and Technology Services Branch (KITS).

[20] Accessible only within NRC IT networks.

Achievement of Outcomes – Other NRC Research Centres

In addition to the examples provided in the evaluation report, the DT Research Centre is also working with NRC research centres that focus on aerospace, automotive, ocean, medical devices, astronomy, quantum materials, and photonic components. DT staff has assisted other research centres as follows:

- Aerospace Research Centre - DT supported three programs: Working and Travelling on Aircraft, Aero 21, and Air Defense Systems. DT projects accounted for 10% of the revenue attracted by the Working and Traveling on Aircraft program in 2015-16.
- Automotive and Surface Transportation Research Centre - DT supported two programs: Fleet Forward and Rail. For Fleet Forward, DT researchers identified patterns in truck traffic in the Montreal Port that may, in a future project, lead to reductions in greenhouse gas emissions.
- Medical Devices Research Centre: In 2015-16, in collaboration with the research centre, LPSS developed tools to enhance the Brain Surgery Simulator and the associated platform to support distributed capture and analysis of simulation results. One outcome of this project was the Rabaska platform, a cloud-based framework for simulator performance result visualization, evaluation and recommendation, with functionalities including (a) simulator performance result visualization, including both NeuroTouch (neurosurgery simulator) and WeldHaptix (welding simulator); (b) a performance-based personalized recommendation module (joint work with Learning System Insights project); and (c) remote simulation launch and collecting the performance results.