NRC·CNRC

NRC.CANADA.CA

Evaluation of NRC'S Automotive and Surface Transportation Research Centre

Office of Audit and Evaluation

June 22, 2020

This report was approved by the NRC's President on June 26, 2020.

Cat. No. NR16-324/1-2020E-PDF
ISBN 978-0-660-35452-1

Table of Contents

Acronyms

- **AMP:** Advanced Manufacturing Program
- **ARC:** Aerospace Research Centre
- **AST:** Automotive and Surface Transportation Research Centre
- **ATC:** Aluminum Technology Centre (AST site)
- **ATSP:** Advanced Transportation System Program
- **CAV/ITS:** Connected and autonomous vehicles / Intelligent transportation systems
- **CSTT:** Centre for Surface Transportation Technology (AST predecessor, transportation-side)
- **DND:** Department of National Defence
- **DT:** Digital Technologies Research Centre
- **ECCC**: Environment and Climate Change Canada
- **EME:** Energy, Mining and Environment Research Centre
- **FF2020:** Fleet Forward 2020 (program)
- **FTE:** Full-time equivalent
- **FWCI:** Field-Weighted Citation Index
- **GBA+:** Gender-based analysis plus
- **GHG:** Greenhouse gas
- **HPC:** High performance computing
- **IMI:** Industrial Materials Institute (AST predecessor, manufacturing-side)
- **IRAP:** Industrial Research Assistance Program
- **IP**: Intellectual property
- **MNE:** Multinational enterprise
- **NGen:** Next Generation Manufacturing Supercluster
- **NRC:** National Research Council of Canada
- **NRCan:** Natural Resources Canada
- **OAE:** Office of Audit and Evaluation
- **OEM:** Original equipment manufacturer
- **OGD:** Other government department (Canadian federal)
- **PERD:** Program for Energy Research and Development (NRCan program)
- **PRC:** Peer review committee
- **RC:** Research centre
- **RTO:** Research and technology organization
- **RVTO**: Rail Vehicle and Track Optimization (program)
- **SME:** Small-to-medium enterprise
- **TC:** Transport Canada
- **TRL:** Technology readiness level
- **VPT:** Vehicle Propulsion Technologies (program)

Executive Summary

The Automotive and Surface Transportation (AST) Research Centre supports the advanced manufacturing and ground transportation sectors to identify, develop and apply relevant science and technology that will ensure Canada's continued prosperity through revolutions in these sectors. It was established in 2013-14 when NRC merged the automotive portfolio of the Industrial Materials Institute (IMI) and the Centre for Surface Transportation Technology (CSTT). AST's strategic research and development (R&D) and technical services activities may be divided into two sections: material processing and manufacturing, and vehicle and transportation systems engineering.

The evaluation covered 2013-14 to 2018-19 and is the first to evaluate AST as a single, integrated research centre. Lines of evidence included a bibliometric study, client survey, data review, document/literature review, external and internal interviews, and a peer review by experts from industry and academia. The key findings and recommendations of the evaluation were as follows:

Relevance: AST is differentiated by its breadth of research (offering it a competitive advantage), as well as its recognized expertise and large-scale facilities. As such, it stands out as unique in Canada, though not internationally. Its research is aligned with the priorities of industry and of the Canadian government, but project selection has tended to be more reactive than strategic, and AST has yet to fully exploit its competitive advantage.

Engagement: AST has employed a variety of engagement strategies, including a successful R&D group model for sectoral engagement. Overall, visibility among and engagement with stakeholders could improve, particularly with the research community in order to effectively implement its proposed Advanced Transportation Systems Program (ATSP).

Resources: AST has had sufficient resources to meet client needs to date, but lacks the critical mass of expertise and facilities needed to move into new and emerging areas.

Scientific excellence and leadership: AST has advanced scientific and technical knowledge in material processing and manufacturing, and in niche areas of transportation engineering (e.g., rail) through technology deployment and optimization.

Impact: AST's work in both the advanced manufacturing and ground transportation sectors is contributing to economic, environmental, and social impacts, as well government policy solutions.

1. AST should articulate a plan that clarifies and promotes the integration of its capabilities in both material processing and manufacturing, and vehicle and transportation systems engineering, and pilot strategies to support this integration. This plan should identify where AST wants to be a leader (and commit resources accordingly), opportunities and risks for Canada posed by mutual disruptions to the advanced manufacturing and ground transportation sectors, and how it will contribute to Canada's competitive advantage in these sectors.
2. AST should increase awareness among and engagement with key stakeholders in new and emerging fields. In particular, it should diversify and broaden its customer base in vehicle and transportation systems engineering, including greater collaboration with key players such as universities in order to access their competencies and facilities.
3. AST should identify and implement strategies to address talent and facility gaps, particularly for its work related to advanced transportation systems. In addition to operationalizing existing HR and facility strategies, AST should explore new strategies to increase capacity to ensure its successful entry into new fields.
4. AST should determine and communicate strategic indicators that measure its contribution to the Canadian economy, demonstrate scientific excellence (using more industry-relevant metrics), and track influence on government operations, policy, and regulations.

INTRODUCTION • AST RESEARCH CENTRE

An evaluation of AST was conducted in 2019-20. It assessed the relevance, engagement, resources, scientific excellence, and impact of the Research Centre. This report provides an overview of the main findings and conclusions as well as recommendations for AST.

Introduction

An evaluation of the AST Research Centre (RC) was conducted in 2019-20, in accordance with the NRC's approved evaluation plan and Treasury Board policies. The evaluation covered 2013-14 to 2018-19 and is the first to evaluate AST as a single, integrated research centre.

This report begins by providing a profile of AST. It then presents the evaluation findings on AST's relevance, stakeholder engagement, resources, scientific excellence, and impact. Following the conclusion are four recommendations for improvements within AST.

Throughout the report, you will see the following symbols:

This is information that is useful to know to help understand the findings.

This is a quote that helps illustrate or support the main findings.

This indicates information that supports equity, diversity, and inclusion and Gender-Based Analysis Plus or GBA+ (i.e., factors that illustrate how diverse groups may experience policies, programs, and initiatives).

The methods from which the findings are drawn from are listed at the bottom of each page.

Sources: Bibliometric study, Client survey, Data review, Document review, External and internal interviews, Peer review

Evaluation Approach

Evaluation Questions

The evaluation questions were developed based on consultations and a review of key documents, and guided the conduct of the evaluation.

1) Is AST focussed in appropriate areas to ensure relevance of the research centre?

2) Has AST engaged the most appropriate clients and collaborators in the most effective ways?

3) To what extent does AST have the capacities, competencies, and facilities to achieve its objectives?

4) To what extent was AST a leader in scientific excellence in the areas of ground transportation R&D (including vehicle testing) and advanced manufacturing?
   a) To what extent is AST positioned to be a leader in advanced ground transportation systems in the future?

5) To what extent has AST contributed to longer term outcomes, i.e.:
   a) the economic growth and prosperity of the Canadian transportation and manufacturing industries?
   b) government operations, policy and regulations?
   c) social and environmental impacts?

Research Methods

Mixed methods were used to maximize the generation of useful, valid and relevant evaluation findings. This approach also allowed for cross-validation of results based on the following methods:

- Bibliometric study (publication and patent citation analysis)
- Client survey (n=128, response rate of 28%)
- Data review (administrative and performance data)
- Document/literature review
- External (n=21) and internal interviews (n=31)
- Peer review by committee of nine experts from academia and industry

See Appendix A for a more detailed methodology including challenges and limitations.

PROFILE • AST RESEARCH CENTRE

AST's vision is to make Canada more competitive through innovations in mobility and manufacturing excellence. It supports several industries including advanced manufacturing, automotive, defence and security, rail, and trucks and buses.

Programs and Services

AST's vision is to make Canada more competitive through innovations in mobility and manufacturing excellence. Its activities may be divided into two sections: material processing and manufacturing; and, vehicle and transportation systems engineering. AST's programs mostly align with one section or the other, though one aligns with both (VPT). AST identifies, develops and applies relevant science and technology that will ensure Canada's continued prosperity through the revolutions in the advanced manufacturing and ground transportation sectors.

Material Processing and Manufacturing

This activity focuses on smart and digital manufacturing, and advanced materials and manufacturing processes. It includes one program of its own, the **Advanced Manufacturing Program (AMP)**, which aims to help position Canada as a leader in smart manufacture. AST's work in this area was previously organized in three programs (Industrial Biomaterials, Light-weighting of Ground Transportation Vehicles and Advanced Manufacturing and Design Systems), which have now been merged to form the AMP. The AMP supports Canada's Next Generation Manufacturing (NGen) Supercluster, a federal initiative to encourage the development of regional ecosystems to create jobs and support innovation.

Cross-cutting programming

Crossing both of AST's sections, the **Vehicle Propulsion Technologies (VPT)** aims to deliver propulsion technology and increase fuel economy. Though most VPT projects have fit under the materials and manufacturing section (e.g., lithium battery, hydrogen fuel cells, and low cost electric motors manufacturing), it has shifted over time to include more transportation engineering projects (e.g., battery safety and performance in the Canadian context to provide evidence for larger adoption of electric vehicles). For analysis and reporting purposes, this program was split at a per-project level to allow for accurate comparisons between sections.

Vehicle and Transportation Systems Engineering

This activity addresses advanced vehicle integration, rail vehicle design, testing and evaluation, dynamic modeling and simulation, wheel/rail interaction, vehicle testing, and connected and autonomous vehicles/intelligent transportation systems (CAV/ITS). It currently includes one service line and two programs:

- **Defence and Security Service Line:** provides a range of technical services to support DND, RCMP, and the Canadian defence industry.
- **Fleet Forward 2020 (FF2020) Program:** aims to improve the operational efficiency of targeted Canadian fleet transportation.
- **Rail Vehicle and Track Optimization (RVTO) Program:** aims to improve operational efficiency and safety of Canadian railways.

AST is developing a new program, the **Advanced Transportation Systems Program (ATSP)**, which will contribute to the transformation of the Canadian surface transportation sector by developing a safer, efficient, more intelligent, more secure and sustainable transportation system. It is intended to launch in 2020-21 and consolidate the RVTO, FF2020 and VPT programs. ATSP will include more CAV/ITS research with planned niche focusses in perception and mapping systems, and adapting technologies to the Canadian context (e.g., signage, conditions).

Why manufacturing *and* transportation? AST was created in April 2013 by merging NRC's Surface Transportation Portfolio with its Automotive Portfolio under a single structure in order to enhance the management of resources and capabilities, and direct manufacturing activities towards the automotive and transportation industries.

Sources: Document Review

Human Resources

As of March 31, 2019, AST had a total of 278 staff, including 19 students, and 24 major facilities and other installations, spread across four sites in Quebec and Ontario. AST also draws on human resources and facilities from NRC's other RCs to complement its own capacities. In 2018-19, other RCs contributed 47 full-time equivalents (FTEs; defined as 1450 hours of labour) to AST's projects and programs. Most of these came from the Aerospace (ARC), Energy, Mining and Environment (EME), and Digital Technology (DT) research centres.

Each site acts as its own research directorate with a Director of R&D at the helm. The Boucherville site also hosts the Director General's office (DG), Operations & Project Management offices, and other common services. The DG reports to the Vice-President, Transportation and Manufacturing.

The Transportation Engineering Centre (see below) was previously the NRC's Centre for Surface Transportation Technology (CSTT), which focussed primarily on technical services and operated under a cost-recovery model. The Saguenay, London, and Boucherville groups (right) previously belonged to the NRC's Industrial Materials Institute (IMI), which was more focussed on strategic R&D. When the IMI was disbanded in 2012-13 into separate portfolios (including the automotive), other RCs were formed from it including EME and Medical Devices (MD), both of which continue to collaborate with AST staff.

Transportation Engineering Centre (TEC), Ottawa, ON

- 48 researchers and 43 technicians in a bilingual setting
- primarily focussed on research and technical services in vehicle and transportation systems engineering

Pictured above: Hard hats used by staff at the TEC in Ottawa, ON.

Aluminum Technology Centre (ATC), Saguenay, QC

- 16 researchers and 12 technicians in a Francophone setting
- focussed on materials/manufacturing (e.g., light weighting)

Manufacturing and Automotive Innovation Hub, London, ON

- 19 researchers and 7 technicians in an Anglophone setting
- primarily focussed on manufacturing, but contributes to some transportation engineering projects (e.g., CAV/ITS)

Materials & Processes, Boucherville, QC

- 60 researchers and 30 technicians in a Francophone setting
- primarily focussed on materials/manufacturing, with some exceptions (e.g., battery safety in transportation systems)

Sources: Data review, Document Review

Facilities

AST's facilities are located at four sites in Quebec and Ontario. It also accesses facilities maintained by other NRC RCs, such as ARC's wind tunnels for testing vehicle aerodynamics and EME's battery testing facilities.

ATC, Saguenay, QC

- industrial scale automated welding, forming and casting laboratories
- scanning electronic microscope and metallography labs
- corrosion and surface treatment labs
- mechanical testing and virtual laboratory for numerical modeling and simulation of processes

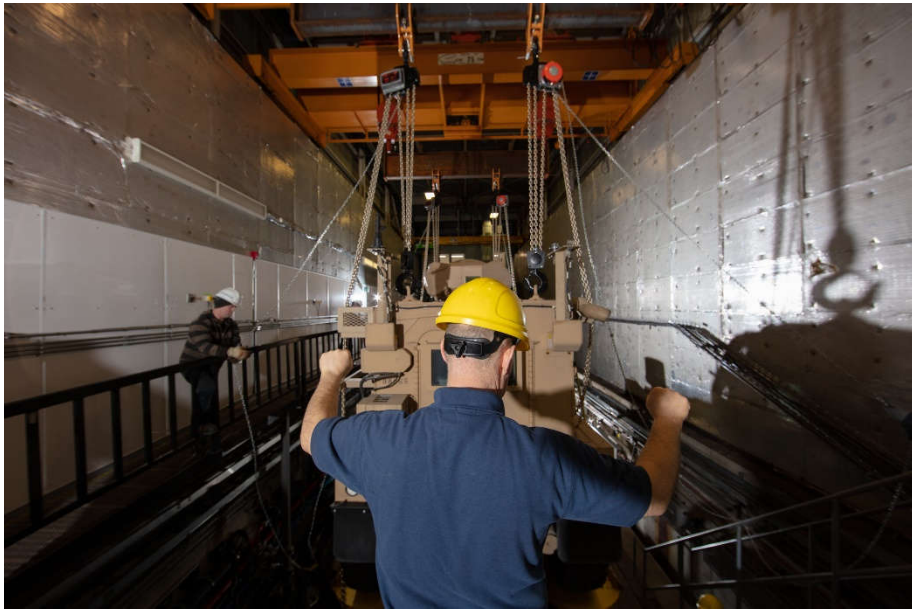
Manufacturing and Automotive Innovation Hub, London, ON

- two experimental vehicle bays with lifts and related automotive shop capabilities
- high crane bay as a manufacturing space, and work cells including advanced automation, laser manufacturing and advanced machining for scale-up and on-site digital factory

Materials & Processes, Boucherville, QC

- advanced polymer matrix composites processing and prototyping at large scale
- lab and pilot scale processing and prototyping of composites and polymers
- high performance computing (HPC) cluster
- lab and pilot scale battery and fuel cell materials, components and cells fabrication and testing
- powder forming facilities
- thermal spray and cold spray facilities

Sources: Data review, Document Review



Pictured above: Vibration testing in the dynamics lab at the TEC.

TEC, Ottawa, ON

- railcar-size climatic chamber (and small chambers)
- heavy vehicle structural dynamics lab
- rail testing facilities
- rail wheel bearing and brake facility
- vehicle field testing and instrumentation equipment (instrumented wheelsets, tilt-table)

Facility Review: AST is also receiving guidance through an NRC-wide facilities review. TEC facilities were reviewed concurrent to this evaluation, but other AST facility reviews are still ongoing. As such, this evaluation has limited its facility-specific findings as AST will be receiving more detailed findings from the review.

Revenues and Expenses

Met technical service targets, but has missed R&D targets

AST sets annual revenue targets for both technical services and strategic R&D (see figure top right). It met or exceeded its technical service targets for the past four years but consistently missed its strategic R&D targets.

Transportation engineering recovering costs, materials/manufacturing focussed on R&D

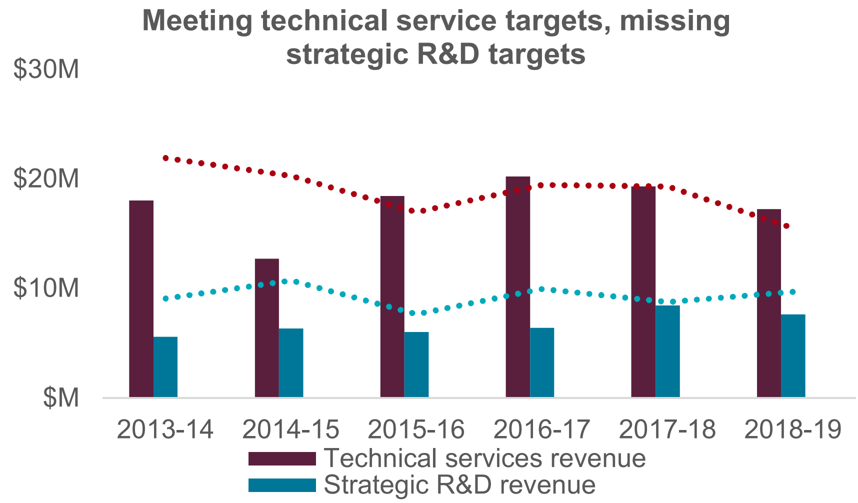
AST earned $149M in revenues in its first six years as a unified RC. Technical services accounted for 71% of revenues, while strategic R&D accounted for 27%. Other sources (2%) included grants and contributions, sale of goods and information products, and lease and use of property. These trends differed significantly by research area (see figure bottom right).

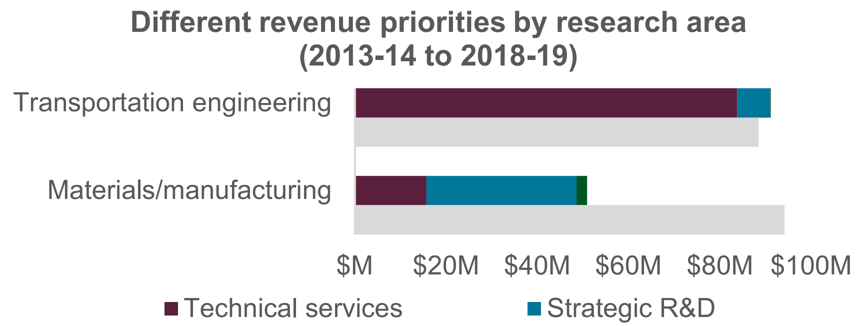
- transportation engineering revenues ($91M) mostly came from technical services (92%), reflective of this section's pre-AST cost-recovery model.
- materials/manufacturing revenues ($51M) mostly came from R&D projects (65%), either for individual clients or its industrial R&D group members. This section also dedicated considerable time to internal R&D projects (no client), and gave in-kind support for R&D group projects; hence its higher expenses.

AST also generated $7M in revenues from other technical service projects that it categorized outside of their transportation and manufacturing programs.

In total, AST had $300M in expenses, most of which (62%) were directly related to transportation engineering and materials/manufacturing projects. The rest (38%) includes costs for other projects, facility and equipment maintenance, RC management, and administration.

Sources: Data review





Strategic R&D versus technical services? Strategic R&D, or research services, consists of collaborative research projects undertaken with partners to de-risk R&D and accelerate commercial development timelines. Technical services consist of projects that assist clients in solving immediate technical problems through the delivery of specialized fee-for-service support (e.g., testing and certifications, calibration, prototyping, demonstrations, scale-up and consulting).

Clients and Collaborators

AST envisions itself as a national convenor, gathering transportation and manufacturing stakeholders across the value chain from academia, government, and industry to breach financial, capabilities, and technical obstacles via collaborative R&D. Between 2013-14 and 2018-19, AST worked with 510 unique organizations, on standalone projects and through its industrial R&D groups. Firstly, AST completed or launched over 1250 standalone projects for 433 unique clients and collaborators. Secondly, it also completed or launched over 120 collaborative projects with its industrial R&D groups, which involved another 71 unique clients, collaborators, and sponsors (see more in the Engagement section, slides 22-23). In total, the R&D groups had 109 members or sponsors (overlapping with standalone clients), who collectively contributed $11.7M to AST in support of R&D (or one-quarter of all R&D revenue).

Over the evaluation period, AST consistently worked with both other government departments (OGDs) and industry, and increasingly with academia and others since 2017-18, though OGD projects accounted for over half of AST's revenue.

Other Government Departments including 15 federal clients, though most of this work was conducted with National Defence (DND), Natural Resources (NRCan), and Transport Canada (TC).

- **$81.7 million in revenues**
- 77% for technical services
- 23% for strategic R&D, including sponsorship of industrial R&D groups

Industry including 448 SMEs and MNEs

- **$60.6 million in revenues**
- 66% for technical services
- 34% for strategic R&D, including contributions to industrial R&D groups
- two-thirds (67%) of standalone projects were conducted for Canadian industry versus one-third (33%) for foreign industry

Academia and others including 47 universities, industry associations, municipal transit agencies and provincial government departments.

- **$4.3 million in revenues**
- 75% for technical services
- 25% for strategic R&D, including sponsorship of industrial R&D groups

Public/private partnerships to support sustainability

AST also conducted 25 projects with a combination of OGD, industry and other collaborators with funding support from NRCan's Program for Energy Research and Development (PERD). PERD is a federal, interdepartmental program that funds R&D designed to ensure a sustainable energy future for Canada. It exclusively funds projects that have both a federal partner (e.g., NRC) and an outside organization (e.g., a Canadian business or university).

Sources: Data review

RELEVANCE • AST RESEARCH CENTRE

Overall finding: With its recognized expertise and large scale facilities, AST stands out as unique in Canada, though not internationally. It may strengthen its position if it leverages its unique characteristics and competitive advantage by further integrating its material processing and manufacturing, and vehicle and transportation engineering capabilities. Overall, AST's research is aligned with the priorities of industry and of the Canadian government. That said, AST has tended to be reactive to client needs rather than proactively identifying and targeting issues of strategic importance to industry. It has opportunities to more directly contribute to Canada's competitive advantage, and to consider end-users from diverse populations in its selection of research activities.

Unique Position and Opportunity within Canada

AST is differentiated by its large scale facilities, recognized expertise, and breadth of research. Its inclusion of both materials processing and manufacturing and vehicle and transportation systems engineering under one centre, and its focus on multiple modalities, offers it a competitive advantage.

AST's breadth of research is an under-exploited competitive advantage

The breadth of AST's activities from materials/manufacturing to transportation engineering, as well as its coverage of different modalities (e.g., rail, road) was highlighted as a competitive advantage for AST. By contrast, TC's Motor Vehicle Test Facility and federal agencies in the United States are focussed on specific modalities and do not bridge manufacturing and transportation.

This competitive advantage has not been fully leveraged, with AST's materials and manufacturing and transportation engineering research teams largely working in silos. These teams have worked more with other RCs than one another. Inhibiting factors included limited integration of transportation programs, limited understanding of one another's competencies, AST's geographic and linguistic divides, and unique service cultures (e.g., testing versus research).

Integrating research domains

AST has taken recent actions to exploit synergies between sections, including:

- transitioning the VPT program from primarily materials/manufacturing to some transportation engineering projects, joining battery manufacturing and vehicle integration expertise
- requiring program leaders from both sections to identify and submit a joint project proposal for PERD funding
- involving materials/manufacturing teams in planning the new ATSP
- identifying other intra-AST labour sharing opportunities (e.g., manufacturing staff contributing to vehicle aerodynamics projects)

AST would further benefit from a clearer vision that responds to common challenges in both the manufacturing and transportation sectors. In practice, this would be supported by more strategic project selection.

Unique capacities within Canada

AST's capacities were found to be unique within Canada though not globally. AST has maintained its relevance with its ability to solve technical problems and conduct strategic R&D for both transportation and manufacturing sector clients.

77% of AST's clients chose them for its **expertise** including:

- recognized capabilities in additive and aluminum manufacturing, rail/wheel interaction, and aerodynamics

50% of AST's clients chose them for its **facilities** including:

- industrial-grade presses and production lines
- structural test facilities and environmental chamber accommodate larger scale vehicles
- access to other NRC RCs' facilities such as aerodynamics and battery safety

Sources: Client survey, Data review, Document Review, External and internal interviews, Peer review

Strategic versus Reactive Project Selection

AST has been more reactive than strategic, particularly in selecting its transportation engineering projects. A shift towards more strategic research that builds on its competitive advantage, would enable AST to have a greater impact for industry and government as opposed to incremental contributions.

Transportation engineering focused on immediate needs

This section of AST has been largely reactive, serving its clients' immediate needs (i.e., testing and technical services). It has not proactively identified issues of strategic importance to surface transportation sectors, including grand challenges that cross modalities. This trend stems from a historically technician-heavy workforce, that previously operated under a cost-recovery model, combined with revenue targets, capital-intensive infrastructure, limited business support, and legacy relationships (i.e., DND).

AST has acted to reorient this section. Firstly, it has proposed a new program (ATSP) to consolidate existing work and transition to more R&D. It is also strategically reviewing its assets and activities to determine if others can take on service projects (particularly for DND) to free up capacity, hiring more researchers and business developers, developing an industrial R&D group for rail, and exploring R&D opportunities with existing clients (as of 2019-20).

Materials/manufacturing R&D may focus more on applications for the transportation sector

AST has aligned this section with future directions of the field, as demonstrated by staff having spent far more time on strategic R&D than technical services. It has been successful at identifying collaborative R&D project opportunities with its materials and manufacturing clients, and industrial R&D group members, creating opportunities for co-authorship and joint presentations.

Per the PRC, this section has more opportunities to link its research (e.g., novel materials and processes) to transportation systems (e.g., transportation networks). The section may also be focussed on too many technologies relative to its size, making it difficult to maintain relevance and a leadership status. Focussing more specifically on transportation applications would build on, or be in addition to previous success in technology deployment and commercialization (see Excellence section; examples on slide 33).

Opportunity to lead on cross-cutting projects that bridge Canadian transportation engineering and materials/manufacturing

As a national convenor, AST can play a leadership role to determine Canada's vision for navigating technological disruptions in the transportation and manufacturing sectors, especially where they intersect. Building on its competitive advantage, AST could position itself as a made-in-Canada solution, and in turn provide Canada with a more competitive and sustainable advantage in both sectors. Though it has begun to integrate its two research domains, the PRC found AST has not done enough to connect disruptions in transportation (e.g., CAV/ITS) and manufacturing (e.g., additives, augmented reality), or those that cross sectors (e.g., digitization, automation) or modalities (e.g., integration of rail and road systems). By selecting projects more strategically and focusing on cross-cutting issues, AST may better align with Canadian industry, giving it an advantage within international markets. This would also strengthen AST's alignment with federal economic priorities.

Sources: Data review, Document Review, External and internal interviews, Peer review

Alignment with Industry Priorities

AST's research is aligned with the current high level priorities of the manufacturing and transportation sectors. It could further support industry by focussing where they intersect.

AMP demonstrated relevance

AST has been researching innovative materials and processes that are relevant to Canadian industry (e.g., light-weighting). It has aligned the AMP with future directions in the field (e.g., additive manufacturing, electrification, greener materials) through industry consultations and via its R&D groups.

Proposed transportation program strategically focussed

The PRC found the ATSP to have a strong, strategic vision, with a timely focus on CAV/ITS, electrification, and alternative fuels. This will better align AST's transportation research with industry priorities. Previously, AST's work in this area was more aligned with the needs of OGDs or client-specific technical needs. Integrating road and rail modalities will be of particular interest to transit systems looking to put this into practice.

Opportunity to extend its competitive advantage to Canadian industry

AST may better contribute to Canadian competitiveness by further exploiting its own competitive advantage. As noted previously, AST should prioritize work that builds on its relative strengths (i.e., breadth of research, multiple modalities) for the benefit of Canadian firms over foreign firms whenever possible. Towards this, the PRC communicated specific examples for cross-cutting research. The PRC warned that if AST does not act on this opportunity, leadership in the advanced manufacturing and transportation sectors will continue to shift to other countries. Moreover, while there are opportunities within a rapidly changing transportation sector for independent testing of new technologies, AST's current model may become less unique as academia is also shifting towards a fee-for-service model.

AST activity aligned with industry priorities

Increased battery capacity

- ✓ electrification and alternate fuels that focuses on improving batteries, electric motors and fuel cells

Increased exports, reduced import dependence

- ✓ work with Canadian automotive OEMs, part suppliers, and the rail sector to improve market competiveness

Procurement of emission free transit vehicles

- ✓ electric bus modelling considering battery capacity

Reduced GHG emissions, improved safety

- ✓ focus on more energy efficient vehicles with light-weight materials such as aluminum and advanced composites, as well as enhanced aerodynamics
- ✓ focus on zero emission enabling technologies such as low-cost electric motors and lithium-based batteries, advanced energy storage technologies and manufacturing of fuel cells for electric vehicles

Reduced operational costs

- ✓ rail engineering and vehicle track interaction for predictive maintenance
- ✓ cheaper, advanced manufacturing processes (e.g., advanced machine vision for monitoring and control)

Sources: Client survey, Document Review, External interviews, Peer review

Alignment with Federal Government Priorities

AST is aligned with the overarching objectives of the NRC and with the priorities of the Government of Canada on the economy, the environment, and national security.

AST aligned with federal priorities

Economic priorities (i.e., increased sales and export diversification in the advanced manufacturing sector)

- ✓ research on additive manufacturing, data engineering and analytics, mechatronics, and robotics

Environmental priorities (i.e., greenhouse gas emission reduction)

- ✓ research on alternative fuels, connected and autonomous vehicles, electrification, intelligent transportation systems, and light-weighting
- ✓ work with TC in support of regulation development and implementation, which supports the adoption of technologies for reducing GHGs
- ✓ work with TC on guidelines for long trains to reduce derailment risk, and thereby reduce environmental impacts

National security

- ✓ provision of testing and technical services to DND related to vehicle performance, instrumentation and hardware, such as communication technologies, for military applications.

Alignment with NRC's three key objectives

- ✓ AST supports **innovative businesses for growth** through its strategic R&D and technical service work with over 250 Canadian businesses, plus its facilitation of industrial R&D groups and work with the NGen Supercluster (see Engagement).
- ✓ AST **advances scientific and technical knowledge** through publishing papers and creating intellectual assets, albeit more in material processing and manufacturing (see Excellence).
- ✓ AST delivers **evidence-based solutions to inform decisions in government priority areas** by working collaboratively with OGDs such as TC and DND.

Other opportunities to support federal priorities

The PRC and external stakeholders identified further opportunities to advance federal priorities. Given its communication technology expertise, AST could play a broader role in supporting other defence priorities such as the cyber-security of the systems used in Canadian military defense fleets. More broadly, AST could form an industrial R&D group with OGDs and provinces focussed on policies that respond to disruptive technologies.

Sources: Document Review, External interviews, Peer review

Consideration of End-Users

There are opportunities for AST to consider end-users from diverse populations in its selection of research activities, particularly for its work in the area of advanced transportation systems as there are implications for the aging population as well as people with disabilities.

AST's programs did not consistently consider diverse populations when selecting projects. Often AST viewed its industry clients as their end-users, and sought to address their needs, which did not necessarily include consideration of diverse populations. That said, some AST projects, particularly those under its transportation engineering projects, are contributing to social impacts that may improve mobility for persons reliant on public transit systems and in Northern or remote communities (see Social Impacts).

Future opportunities for new transportation program to support mobility

AST may support aging populations and persons with disabilities with new technologies in choosing the direction of its new ATSP.

Challenges facing aging populations & persons with disabilities	Potential CAV/ITS solutions
Difficulties in perceiving and analyzing solutions while driving	Intelligent cruise control
Inaccurate judgement of speed and distance while driving	Automated lane changing
Mitigating fatigue while driving	Driver condition monitoring system
Operational inefficiencies of transit systems	Integration of transportation networks (e.g., roads, transit, cycling)

New facilities for advanced manufacturing to involve diverse populations

More recently, AST has taken preliminary steps in considering how its material processing and manufacturing work may impact diverse populations. In 2019, it committed to considering diverse populations as part of its revised program plan for AMP. Towards this, it is in the process of opening a new advanced manufacturing facility in Winnipeg, Manitoba, where it is partnering with both University of Manitoba and Red River College. These institutions have large Indigenous student bodies which will bring new perspectives to AMP.

Why is considering diverse populations important? The Canadian Federal Government's priority is to consider GBA+ in all of its activities. GBA+ assess how diverse people (e.g., gender, race, ethnicity, religion, age, physical differences etc.) may experience policies, programs and initiatives.

Sources: Document Review, Internal interviews

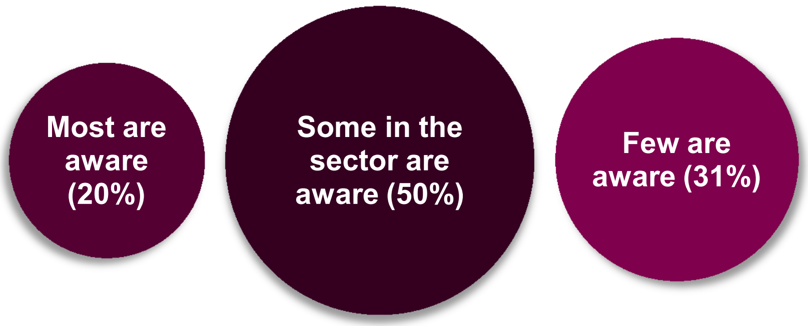
ENGAGEMENT • AST RESEARCH CENTRE

Overall finding: AST's visibility among and engagement with stakeholders could be greater, particularly in the research community. On one hand, AST's work in material processing and manufacturing has involved a broad and diversified range of players throughout the manufacturing value chain. This has been facilitated significantly by its industrial R&D groups, as well as industry consultations and working with the NGen Supercluster. On the other hand, AST's work in vehicle and transportation systems engineering was primarily to support OGDs, with relatively low engagement with academia and Canadian industry. These gaps must be addressed in order to effectively implement its proposed ATSP.

Engagement Strategies and Awareness

Awareness of AST has room to grow. It has employed a variety of strategies, including a unique R&D group model, that could be implemented across AST programs in order to increase engagement.

The level of awareness of AST, per its clients



Note: Percentages do not add up to 100% due to rounding

AST's outreach efforts have been somewhat successful. Strategies have included one-on-one outreach, participation in events, conferences, and local and regional initiatives, relationship development with SMEs through NRC-IRAP, publishing, and founding and leading industrial R&D groups (see next slide). Awareness of AST in the manufacturing sector may have been inhibited somewhat by its branding (e.g., exclusion of 'manufacturing' from its name).

Staff from both AST sections participate in national and international committees. Materials/manufacturing staff tended to be on academic committees (e.g., Thermal Spray Society) while transportation staff tended to be on Canadian and US federal committees (e.g., US Dept. of Transportation), though this was not tracked systematically.

New opportunities to engage research community and industry

More participation in the research community, such as greater publications and attendance at events/conferences, could raise awareness. Opportunities to attend conferences/trade shows should be extended to junior and technical staff to keep them abreast of emerging issues, and to add more total connections between AST and academia. The PRC also highlighted that publishing and revenues should not be seen as competing priorities, as the former may attract new clients.

Other engagement strategies highlighted by surveyed client as the most effective included increased outreach by executives, advertising in trade publications, and more NRC webinars.

Sources: Bibliometric study, Client survey, Document Review, External and internal interviews, Peer review

Industrial R&D Groups

AST's industrial R&D groups have proven effective at fostering collaboration. They are a unique innovation that AST has successfully spearheaded at NRC.

R&D groups an effective model to engage industry

NRC facilitates collaborative, multi-client industrial groups that allow members to share R&D costs and risks. Members pay dues and collectively identify and deliver R&D projects, while other public and industry stakeholders provide sponsorship. This model is an effective means to expand and sustain engagement, and ensure research priorities are aligned with industry trends.

AST has eight of NRC's nine R&D groups, mostly associated with materials and manufacturing subsectors. Collectively, members and sponsors provided $11.7M in revenues during the evaluation period, accounting for over one-fifth of the manufacturing section's total revenues. Members received access to:

- ✓ a network of peers in a non-competitive environment
- ✓ collaborative projects at an affordable cost
- ✓ NRC's R&D experts, facilities, and technological capabilities
- ✓ technologies, intellectual property (IP) and R&D results (see slide 34 for more on IP access for members)

Groups engaged 100+ materials/manufacturing businesses

Industrial R&D groups have expanded AST's reach throughout the manufacturing value chain, including a large number of businesses that had not otherwise worked with AST (two-thirds of members). Groups active during the evaluation period include:

- ALTec (Aluminum manufacturing technologies)
- CSAM (Cold spray additive manufacturing)
- LiBTec (Lithium battery technology)
- SIGBlow (Blow molding modelling and simulation)
- SNAP Composites (Short, novel, affordable processes for composite manufacturing)
- STAMP Composites (Stamping technology for automotive manufacturing and processing of composites)
- Surftec (Advanced surface engineering technologies for harsh environment applications)

Most group members were Canadian businesses (except for SIGBlow). Sponsors included NRCan, as well as provincial agencies and industry associations. The latter two are mainly from Quebec where industrial research consortia provide strategic and financial support to their respective sectors (their support to the groups was purely financial).

New groups to build on transportation engineering expertise

The transportation engineering section launched its first R&D group in 2019-20 with a focus on the rail sector (see next slide). The R&D group model may be used to address engagement gaps in this sector. AST plans to launch at least one new group over the next five years. The PRC suggested new groups to build on AST's strengths such as: a regulatory/policy group with OGDs and provinces; a CAV group with policy and industry players; and, heavy and light rail transit groups with operators.

Sources: Data review, Document Review, External and internal interviews, Peer review

Transportation Engineering Stakeholders

AST's work in vehicle and transportation systems engineering has largely served a few key accounts, and engagement with academia and Canadian industry has been low. As it ramps up CAV/ITS research, AST will need to broaden their client base to include key players in these spheres.

Most work with two federal departments, one foreign business

AST's transportation engineering projects have mostly served three clients, DND (45% of revenues), TC (22%), and an American railcar manufacturer (8%). Remaining revenues came from projects with 123 other clients and collaborators. In industry, it worked with an equal number of Canadian and foreign firms, but did more work for the latter. Most work with other organizations was with Canadian and American transit agencies.

Rail group attracting new collaborators

AST launched an industrial R&D group regarding wheel-shelling called **RailWheelS** in 2019-20. The PRC said it was promising at this early stage as AST had attracted a mix of both Canadian and foreign industry involvement but it was concerned that AST was missing Canadian Class 1 operators such as CN and CP.

AST is also a sponsoring partner of the **International Collaborative Research Initiative (ICRI) on Rolling Contact Fatigue and Wear of Rails and Wheels**, an informal group of industry, academia, and OGDs. The rail team leads the initiative from a management perspective and also provides technical leadership and support to the international collaborative R&D projects.

Low engagement with Canadian industry and academia

Compared to materials/manufacturing, AST has been relatively less successful expanding its reach in the transportation sector. Engagement was inhibited by limited business development support over the evaluation time period (e.g., insufficient resources and turnover among client relationship leaders), though it now has dedicated business development support for this area. Transportation programs and service lines each had unique areas where engagement was low or had room for improvement:

- **Trucking and heavy duty vehicles:** For-hire fleet operators; only indirectly via industry associations (e.g., Canadian Transportation Equipment Association).
- **Rail:** Rail car manufacturers and other firms in rail R&D.
- **Defence:** Industry overall, but particularly MNEs.

AST has engaged relatively little with universities in transportation engineering, such as major players in CAV/ITS (e.g., McMaster, UOIT, Waterloo). The PRC recommended that partnerships with academia would help AST supplement capacity and facilitate a shift towards the more fundamental, intermodal research it plans to pursue under the ATSP. It would also increase its market intelligence, ensuring they initiate unique research and distinguish themselves.

Sources: Data review, External and internal interviews, Peer review

Materials/Manufacturing Stakeholders

AST's work in material processing and manufacturing has engaged an appropriate mix of clients and collaborators (e.g. small and large businesses, Canadian and foreign, OGDs, and universities).

Pictured above: An AST researcher and a SNAP Composites R&D group member examine a compression molded vehicle component.

Broad engagement, no significant gaps

AST had 290 unique clients and collaborators for its material processing and manufacturing projects. It worked primarily with Canadian industry (45% of revenues), followed by foreign industry (27%) and OGDs (26%). It also worked with universities and industry associations on multi-partner projects (i.e., with a Canadian business).

Co-authorship with academia, industry

In addition to projects, material processing and manufacturing staff co-authored publications with external partners. AST's collaboration rate with industry (20% of publications) was twice the NRC average (11%). Most academic collaborators were based in Quebec, a trend driven by location and third-party funding requirements (i.e., industrial research consortia in Quebec that mandate collaboration with institutions in that province).

New opportunities to engage

AST is working with the NGen Supercluster, a non-profit industry-led consortia that matches federal funding to businesses and other stakeholders, based in southwestern Ontario. There is potential for NGen to connect AST with more Canadian SMEs, particularly through AST-London, but this has yet to be realized (e.g., five collaborative projects were identified but unapproved as of 2018-19).

Sources: Data review, Document review, External and internal interviews, Peer review

RESOURCES • AST RESEARCH CENTRE

Overall finding: AST has had sufficient resources to meet client needs to date, and has been building and transitioning its capabilities for R&D in new and emerging areas. However, AST's ambitions outweigh their capacity and budget forecast. At this critical point, AST will need to identify and implement new strategies to address talent and facility gaps in order to meet emerging client needs and to position AST as a research leader.

Demonstrated Agility and Strategic Growth

Over the evaluation period, AST's capacity met client needs. It has began to build and transition its capacities from technical services to strategic R&D, in order to enter new and emerging areas.

Meeting client needs

AST has had sufficient capacity to fulfill its existing lines of work. Most clients surveyed (70%) felt NRC has had the necessary expertise to fulfill project objectives. The PRC was impressed by AST's agility in responding to a wide range of technology requests.

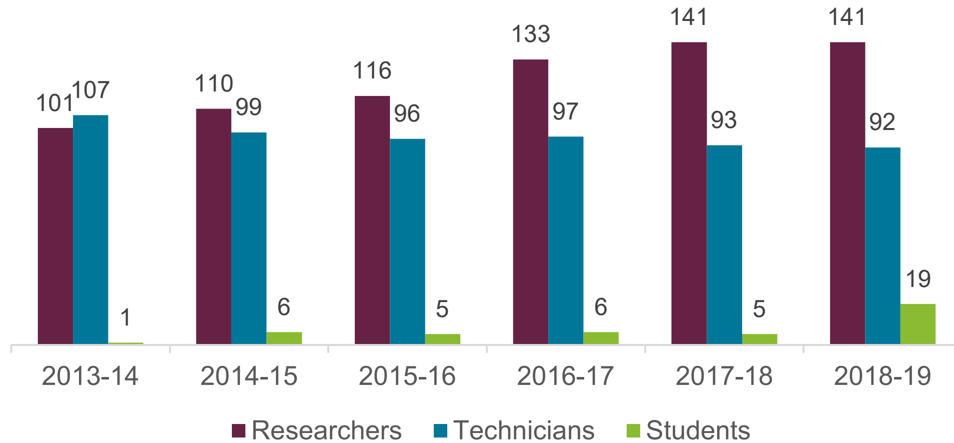
Accessing broader NRC expertise

AST has built and maintained its capacity by drawing on outside labour. Overall, one quarter (26%) of labour for its projects came from other RCs, a trend consistent over the evaluation period. In particular, AST:

- relied on EME and its expertise in energy storage for half of the labour needed to implement VPT projects
- drew from ARC for a mix of programs, but most notably for FF2020
- has increasingly drawn on DT as projects require more digitization expertise

This poses a risk for AST. To date, staff reported some challenges in delineating research areas and accounting for revenue attribution. Also, AST may find itself competing for these resources as NRC launches new, multidisciplinary programs that cross RCs.

Hiring more researchers to increase R&D



Note: This figure excludes management and administration.

New researchers, students in emerging fields in materials/manufacturing

AST grew this section from 120 to 159 staff. After an NRC-wide cap on budgets was imposed in 2018-19, it continued building capacity by taking on more students. The directorate in AST-London has been budgeted to hire new staff to grow its manufacturing and CAV labs, thus supporting both sections of AST.

Transitioning the TEC towards R&D

AST has been strategically replacing technicians that have left the NRC with researchers, while maintaining relatively stable staff numbers (up from 89 to 93). In 2013-14, 38% of the TEC staff in Ottawa were researchers; by 2018-19, their share increased to 49%.

Sources: Client survey, Data review, External and internal interviews, Peer review

Gaps in Expertise and Capacity Pressures

AST lacks the competencies needed to exploit its innovations in material processing and manufacturing, or to enact the vision of the ATSP. Existing staff have had insufficient opportunities to develop new competencies due to competing revenue priorities.

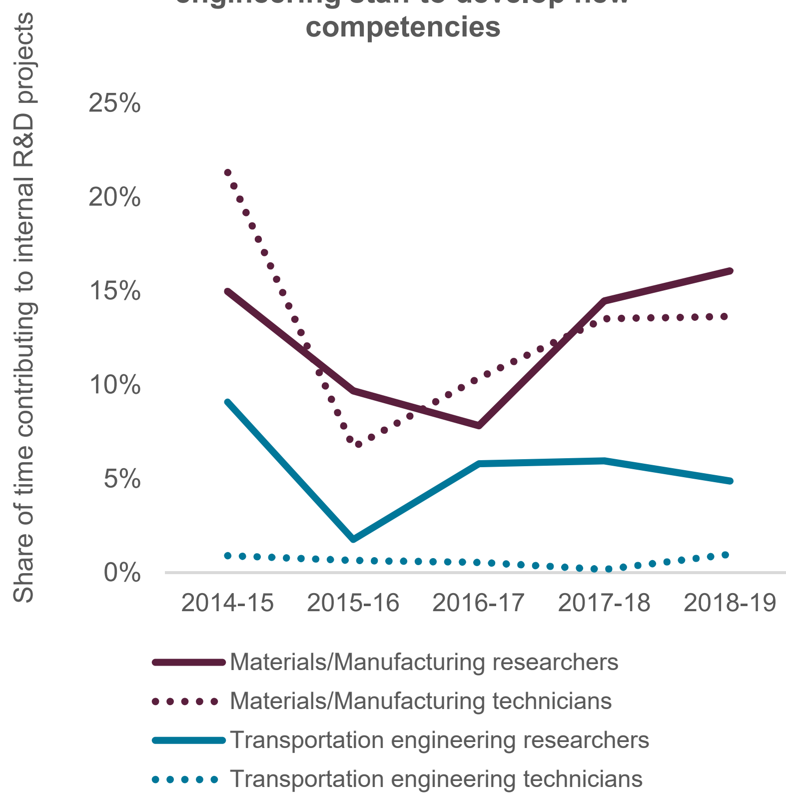
Missing expertise and critical mass to respond to emerging demands

Staff reported that they had managed to meet clients needs over the evaluation period but are ill-positioned to respond to new or more complex demands. Moreover, almost half of clients (48%) said AST had some capacity gaps. Identified gaps included digital fields such as artificial intelligence (AI), CAV/ITS, cyber-security, and modeling and simulation. In some of these areas (e.g., AI, modeling and simulation) AST has expert staff but lack critical mass. Gaps have been mitigated in part through strategic hiring, accessing labour from other NRC RCs, and internal competency development.

Materials/manufacturing staff given more development opportunities

AST has developed and broadened staff competencies through exploratory R&D projects but has had difficulty balancing this with revenue generation. Though staff have been afforded more time for these internal projects (after a major decrease in 2015-16; see right), transportation engineering staff, especially technicians, have had limited opportunities to develop new competencies. This may undermine the transportation engineering section's ability to respond to emerging industry needs and deliver the ATSP in the short-term (i.e., before it can hire new researchers). By contrast, materials/manufacturing staff have been afforded more development opportunities, in areas such as machine learning and manufacturing digitalization, supporting their ability to conduct R&D that addresses emerging client needs.

Limited opportunities for transportation engineering staff to develop new competencies



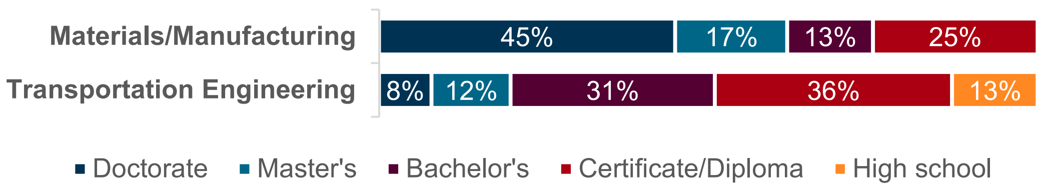
Note: Detailed timesheet data was not available for 2013-14.

Sources: Client survey, Data review, External and internal interviews, Peer review

Demographics and Education

The materials/manufacturing and transportation engineering teams have very different educational backgrounds, which align with their distinct cultures (i.e., R&D focus versus cost recovery). AST has begun to expand its capabilities by hiring more students and strategically replacing departing staff, which also provides an opportunity to improve employment diversity and equity.

Differences in AST sections' educational profiles



Note: Data limited to researchers and technicians as of 2018-19, excluding management and administration, and those who did not have education on file (10% of total scientific and technical staff).

Hiring next generation of young and diverse researchers

AST met its 2018-19 equity targets for women (i.e., 22%). Of AST management, 29% were women. Of researchers and technicians, 15% were women. Of administration, 95% were women.

Gender split by section, with 19% of manufacturing researchers and technicians versus 7% of transportation engineering.

Other equity groups were underrepresented at AST, based on self-identifications volunteered by staff versus workforce availability per Statistics Canada. Visible minorities made up 14% of staff, below the 22% target. Targets for Aboriginal people (2%), and persons with disabilities (4%) were also not achieved (actual figures suppressed to maintain individual privacy).

Hiring more students may improve equity in the long-run as many co-op students find permanent positions with AST. In 2018-19, 42% of students were women. Partnerships with schools with large Indigenous populations are also being developed (i.e., University of Manitoba, Red River College).

Materials/manufacturing teams

These teams are scientist-heavy, and tend to be very focussed in specific areas and lower TRL research. The PRC suggested AST could supplement these teams with new staff with more business acumen and sufficient technical understanding (e.g., Master's level graduates), in order to support greater commercialization of AST's innovations in materials and processes

Transportation engineering teams

These teams are lacking graduate-level researchers, and tend to be focussed on technical services. Attracting topic-diverse researchers would enable AST to respond to changing directions and exploit new opportunities. Hiring recognized leaders may attract more interest from industry and other sector players.

Retire-and-replace

Many employees are mid-to-late career. By 2024, 28% of AST's staff will be eligible to retire, and nearly half (44%) by 2029. This aligns with NRC overall. AST's staffing strategy has, in part, relied on ongoing turnover to transition its workforce towards more R&D. However, fewer staff have retired than anticipated, slowing this process and contributing to budget pressures.

Sources: Data review, Internal interviews, Peer review

Equipment and Facilities

AST's facilities met the needs of most clients, despite lacking planned investments. Equipment and facility gaps may inhibit AST's ability to address emerging needs and position itself as a leader.

Investment lacking, but clients satisfied

Most clients surveyed (61%) felt NRC has the facilities to fulfill their objectives, though 37% said they had some gaps. External stakeholders described the facilities as appropriate, with some calling them 'state-of-the-art.' The PRC described the facilities as being of a good calibre and sufficient for a range of different industries, technologies, and vehicles. However they observed that AST had invested in current facilities rather than moving on and into new facilities to support future research priorities. To position itself among global leaders in China, Europe and the US, AST needs to make major investments, specifically to maintain relevance in rail.

Throughout most of the evaluation period, AST was unable to consistently secure the major capital it needed in order to invest in and upgrade its facilities, instead relying on interim investments and third-party facilities to meet its needs. In 2018-19, however, it did secure major capital to build a new battery manufacturing facility in Boucherville for its VPT program.

Materials/manufacturing needs new equipment, exploring partnerships

Staff say it is difficult for them to innovate with their current facilities. They have dedicated time to adapting existing equipment to meet client needs but still have had to turn away some new business opportunities. Specific gaps include:

- digital manufacturing equipment to create a demonstration facility of a Digital Factory at AST-London
- HPC and IT software, namely computer clusters and digital simulation software
- replacements for its laser system for machining and scanning electron microscope

AST has relied on academia for specialized equipment. It is exploring arrangements to access or upgrade facilities by partnering with universities to leverage third-party funds.

Scope of transportation engineering work limited by existing facilities

Staff reported some facilities are out-of-date and missing features, preventing them from competing with others and possibly diminishing client confidence. Clients interviewed were mostly satisfied with facilities but noted they cannot do some large-scale tests. Specific gaps include:

- climatic chamber requires regular repairs, lacks solar simulation
- wind tunnels too small fit a full-length tractor trailer
- facilities for freight railcars too small to conduct a fatigue test for all load conditions

AST has relied on TC's Motor Vehicle Testing Facility for on-road testing to cover some facility gaps.

Sources: Client survey, Data review, Internal and external interviews, Peer review

Budget Limitations

AST is at a critical point as it is required to reduce its spending at the same time intends to enter new research areas. AST will need to strategically invest in new resources and facilities, and leverage partnerships, that build upon its competitive advantage (i.e., breadth of research, multiple modalities) rather than continue business-as-usual.

Increasing salaries poses budget challenge for AST

AST management expressed concern that ongoing expenses may constrain its ability to build and transition its R&D capabilities, a concern echoed by the PRC. Salaries, which have increased over recent years, were identified as a key driver of rising costs that restrict AST's ability to invest in new capabilities. Over the same time, AST has spent less than it had planned on minor capital investments (see table at right).

Causes for AST's increasing salary costs lay in part outside of AST's control. NRC's budget reallocation in 2017-18 capped operating budgets. Salaries still grew as anticipated retirements of more highly paid staff did not occur (e.g., in 2018-19, 11% were eligible to retire but only 2% did). Moreover, base salary rose over the last two years due to the ongoing climb, by employees, in their respective salary scale.

Managing its increasing costs will be a challenge for AST as the RC is expected to reduce its costs in the short-term. As part of the NRC 2017-18 budget reallocation, all RCs were required to reduce spending by 10% over the next five years. AST does have HR and facility strategies in place to guide this process, but additional strategies may be necessary in order for it to deliver on its new program in light of budget limitations.

Salary growth may constrain investments in new capabilities to support R&D transition

	FY14	FY15	FY16	FY17	FY18	FY19
Total expenses	**$45.3M**	**$43.9M**	**$47.2M**	**$51.7M**	**$56.8M**	**$55.2M**
Salaries	$26.5M	$25.2M	$26.8M	$27.6M	$28.5M	$31.0M*
% of total	*59%*	*57%*	*57%*	*53%*	*50%*	*56%*
Minor capital investments	$3.9M	$3.1M	$3.3M	$4.0M	$2.0M	$2.2M
% of total	*9%*	*7%*	*7%*	*8%*	*4%*	*4%*

*Total expenses in 2018-19 were within budget, but salaries were 2% over budget.

Strategic investments, partnerships necessary for success

Capital investments are necessary if AST wishes to position itself as a leader. AST needs a vision and plan to better integrate its two sections and prioritize resource allocation accordingly. Beyond operationalizing existing HR and facility strategies, the PRC stressed that AST should pursue new strategies, such as investing in resources that support both research domains, partnering with more third-parties to access both competencies and facilities, and, where possible, using more modeling and simulation to reduce resource-intensive physical testing.

Sources: Data review, Document review, External and internal interviews, Peer review

EXCELLENCE • AST RESEARCH CENTRE

Overall finding: AST has demonstrated scientific excellence in material processing and manufacturing, and transportation engineering in specific niche areas. This excellence has not been demonstrated through scientific publications, but rather through the development and optimization of technologies and process with the potential to advance the automotive and surface transportation sectors. AST will need to address resource, focus, and engagement issues in order to become a leader in advanced ground transportation systems.

Expertise, Innovation and Technology Deployment

AST is recognized for its expertise in both materials/manufacturing and transportation engineering in specific niche areas. It has optimized and developed new technologies and processes with the potential to advance both sectors.

Material processing and manufacturing

AST has demonstrated scientific excellence in areas such additive manufacturing, batteries, biomaterials, cold spray, light-weighting, and software development for moulding. The PRC also recognized AST's significant promise in stamping and forming of printable electronics, a relatively new area for AST. Specific contributions to the fields includes:

New fabrication method for electric motors, namely cold spray technology, to fabricate magnetic materials such as permanent magnet components. This has the potential to improve performance and reduce costs, as demonstrated by a Canadian SME that deployed new components designed with this technology.

Developed bio-alternative to petroleum-based materials using lignin pellets and lignin-polymer materials recycled from pulp and paper manufacturing by-products. This is a natural alternative to petroleum-based thermoplastics with a short time to market. A trial with agricultural films is underway.

Vehicle and transportation systems engineering

AST's rail research is extensive and the team has a historically strong reputation. Its work on instrumented wheelsets is particularly noteworthy. It was also recognized for its innovative test methods for aerodynamics of rail and heavy duty vehicles. Specific contributions to the field include:

Municipal transit authority in a major American city deployed AST autonomous instrumented wheelset technology on its subway line to monitor vehicle/track health and identify derailment potential. The client also described AST's work on rolling rail contact fatigue as ahead of Transportation Technology Centre, Inc., who uses NRC's instrumented wheelset technology for evaluating new railcars design.

New testing protocol for electric vehicle safety, developed by AST, was adapted by an international OEM into its design of future electric vehicle battery packs.

Pictured above: NRC's instrumented wheelset technology used at an American transit authority.

Sources: Document review, External and internal interviews, Peer review

Intellectual Property

AST has contributed to the advancement of knowledge through its inventions and new IP. Its sharing of IP through the ALTec R&D group is an innovative practice to support members and demonstrate leadership.

AST inventing, disclosing IP for material processing and manufacturing

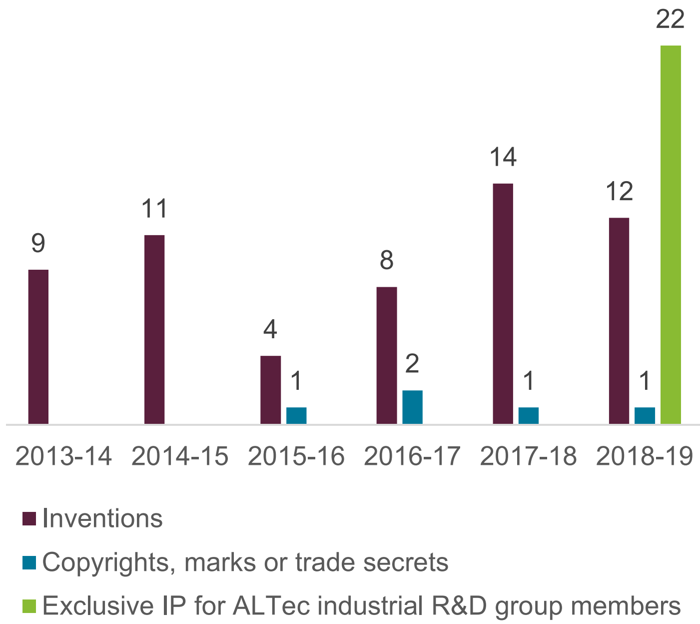
As of 2018-19, AST was one of NRC's most prolific generators of new IP. Throughout the evaluation period, AST disclosed 85 new inventions or other IP (see figure at right), nearly all of which related to materials/manufacturing. It also filed patent applications for 17 unique inventions, all but one of which related to materials/manufacturing. As of Summer 2019, three of these applications resulted in an issued patent.

On average, AST disclosed 10 new inventions each year. The plurality was related to metal products manufacturing (4 per year), followed by polymer and composites products (3), and vehicle propulsion technologies (2). While most of these inventions had applications for material/manufacturing, three VPT inventions had application for vehicle and transportation systems engineering.

AST spearheading best practice for knowledge distribution to industry

AST has generated and shared IP through its industrial R&D group model. In 2018-19, the ATC in Saguenay catalogued 22 knowledge products, including algorithms, methodologies, and simulation tools, for exclusive use by members of the ALTec industrial R&D group. This accumulated 'know-how' represented five years of internal R&D conducted for the group. While AST and other RCs have generated and disclosed similar types of IP (e.g., methods), none have done so in this manner, with AST effectively creating an exclusive knowledge catalogue for innovative businesses. The PRC highlighted this as a best practice that AST's other industrial R&D groups should emulate.

AST consistently developing new innovations



Note: This is limited to reported IP and would exclude any inventions AST has chosen not to disclose at this time.

Sources: Data review, Internal interviews, Peer review

Scientific Influence

AST has deployed new technology and IP that has had a positive impact on clients, but the scientific impact of its publications has been lower than its comparators.

Most publications in material processing and manufacturing

Materials/manufacturing staff produced 327 publications versus only 27 from transportation engineering, between 2013 and 2018. Output by the former however declined after 2013 due to an NRC-wide shift towards technical services and increasing revenue targets (i.e., 100 materials/manufacturing publications in 2013 versus 36 in 2018). The transportation engineering section has improved somewhat as they were already focussed on cost-recovery activity (no publications in 2013), but have begun reorienting towards R&D (9 publications in 2018). Per the PRC, publishing should be part of its engagement and business growth strategy, rather than in competition with it, as publications boost their authors' reputation and profile.

Relatively low impact within academia

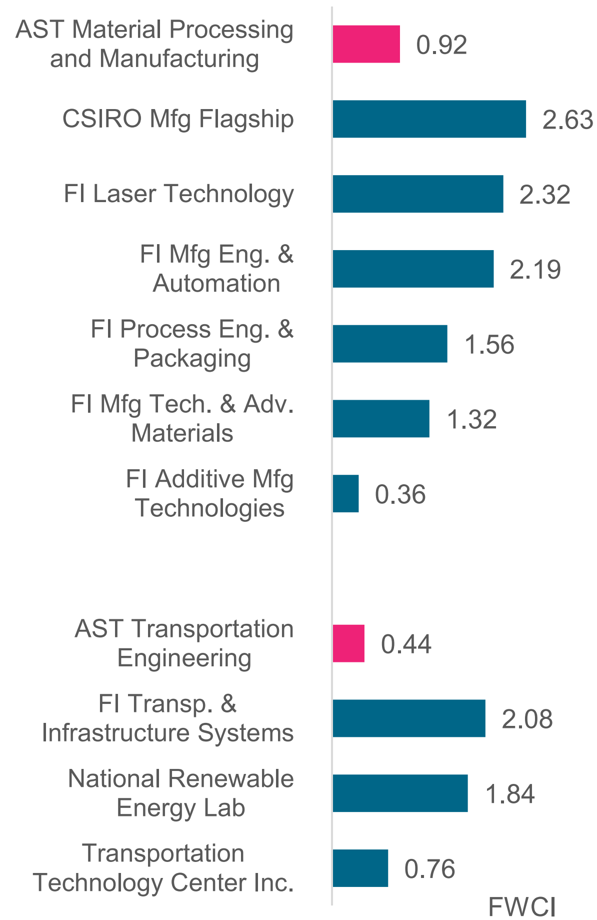
AST publications were not well cited relative to NRC nor Canada overall. While Canada and the NRC both averaged FWCI scores of 1.5 for the six-year evaluation period, AST averaged only 0.9. Both sections lagged behind most comparator (see figure right). Additionally, its publications were also less cited in patents (14 per 1,000 publications) relative to NRC (48) or Canada (25).

Opportunity to establish industry-relevant outputs and targets

As AST's target audience is industry, scientific excellence targets should be expanded beyond publication metrics to include indicators that capture its influence on innovative businesses (e.g., conference attendance, trade show presentations, and technology demonstration and deployment). This would be especially relevant for its transportation engineering section, which has been focussed on technical services over publication.

Sources: Bibliometric study, Peer review

Impact lags comparators



Notes: Bibliometric analysis was conducted by calendar year, not fiscal year, and covered all publications from 2013 through 2018. FI are Fraunhofer Institutes.

What is the Field-Weighted Citation Index? The FWCI is a normalized indicator to gauge relative performance of a publication in terms of citations. It takes into consideration the number of publications and publication norms in different research domains.

Position for Future Leadership

AST's potential to lead in advanced ground transportation systems is inhibited by resource gaps, limited examination of intermodal systems or cross-cutting problems to date, and isolation from key leaders in the field. Attaining leadership will demand both internal and external collaboration.

Promising, relevant research direction

The proposed ATSP will focus on four research domains, namely rail, automotive and specialized mobility (e.g., trucks and heavy duty vehicles), CAV/ITS, and electrification and alternate fuels. The PRC and external stakeholders concurred that the ATSP has a promising, relevant research direction overall (e.g., connectivity, automation, sustainability) and that its planned niches in perception and mapping systems, and adapting technologies to the Canadian context (e.g., signage, conditions), are appropriate.

AST's research activity to-date has helped position it to be a leader in advanced transportation systems. Its work in rail, in some areas, is leading-edge within North America (e.g., instrumented wheelset). AST is also well-positioned in research areas such as CAV, for which is it hiring, and electrification, for which it is building new facilities.

Nascent capacities in competitive fields

Although it is well-positioned and has a promising direction, AST lacks the resources (e.g., competencies, critical mass, facilities) to fulfill the ATSP's objectives. For instance, the emphases on CAV/ITS and electrification—albeit appropriate—are nascent and more resources will be necessary. This may be mitigated in part through collaboration with academia, but will also require investments in experimental facilities.

Limited examination of intermodal systems, cross-cutting problems

There has been little synergy between the current transportation programs (i.e., FF2020, RVTO, and VPT). AST's transportation engineering teams tended to work in mode-specific silos rather than collaborate. The PRC identified synergistic research opportunities such as rail and road systems integration, common vehicle dynamics problems related to curving, and infrastructure layout of transportation networks.

Isolated from key leaders in the field

AST has had insufficient collaboration with academia in the area of vehicle and transportation systems engineering. This is essential to engage in cutting edge research and develop expertise. This should be seen as an opportunity to collaborate rather than compete. Potential collaborators identified by the PRC include:

- Waterloo Centre for Automotive Research at the University of Waterloo
- Institute for Automotive Research and Technology at McMaster University
- Electronic Vehicle Research Centre at the University of Toronto

To facilitate collaborations with universities, AST could set up master research agreements between the universities, industry and AST to define how IP is handled, technology is transferred and how joint publications can be produced.

Sources: Bibliometric study, Data review, Document review, External and internal interviews, Peer review

IMPACT • AST RESEARCH CENTRE

Overall finding: Through its work in both material processing and manufacturing, and vehicle and transportation systems engineering, AST has contributed to the economic growth and prosperity of the Canadian manufacturing and transportation industries, supported government operations, policy, and regulations, and contributed to longer term environmental impacts. Additionally, its work in transportation engineering is contributing to a safer, more secure, more efficient, and more reliable Canadian transportation system, and its work in manufacturing is positioned to create new, better career opportunities to Canadians in advanced manufacturing. That said, AST has opportunities to better track its achievements.

Economic Impact

AST positively impacted its industry clients, who reported adopting new technologies, releasing new or improved products, and increasing their competitiveness. Its industrial R&D groups provided members increased innovation capacity and opportunities to strike new partnerships in the manufacturing sector.

Different impacts between transportation and manufacturing clients

Transportation engineering clients were more likely to report increased competitiveness, access to new markets, and reduced product-time-to-market. For example, AST provided a Canadian rail operator with evidence of their routes' superior ride quality, supporting their case to have dedicated tracks. AST also helped industry meet regulations, for instance working with the Canadian Transportation Equipment Association to develop rear impact guard designs that meet TC regulations.

Materials/manufacturing clients were more likely to report increased productivity, and new partnerships. For example, work on light-weighting for flight decks of SUVs and minivans led to a new value chain including multiple Canadian firms.

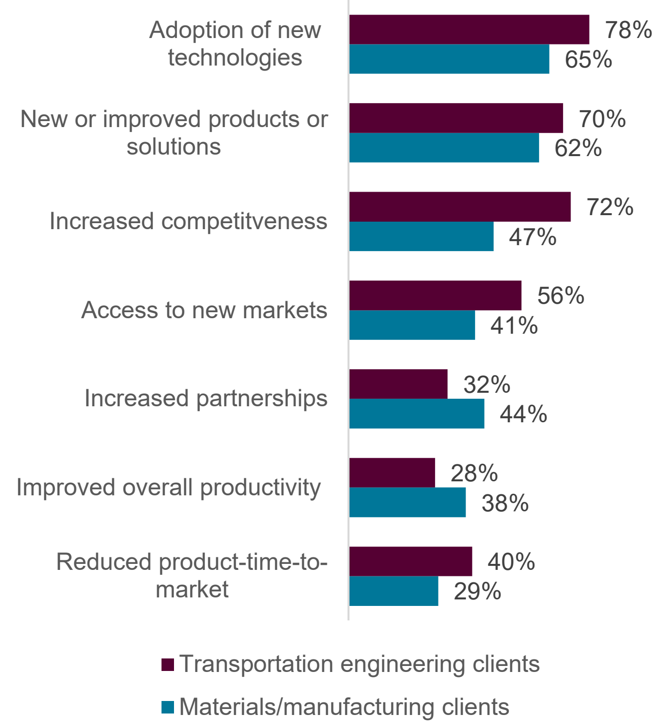
R&D groups increased innovation capacity, partnership opportunities

R&D groups gave members opportunities to collaborate, and stay abreast of the latest developments in their fields. Member surveys found that participants increased innovation capacity (83% of ALTec members) and led to new to business connections (88% of Surftec members). Interviewees welcomed access to unique and useful technologies (e.g., SIGBlow software, ALTec IP catalogue).

Opportunity to conduct follow-up on and track economic impact

If AST were to track foreign investment, revenue growth, and employment growth, among its industry clients and R&D group members, it would be able to better understand how and where it is having the greatest economic impact for Canada.

Positive impacts for industry



***"AST put together a fantastic consortium of end-users such as ourselves. We were able to take that information and spin it off into a program to further advance the technology for our applications."* – Industrial R&D group member**

Sources: Client survey, Data review, External interviews, Industrial R&D group member surveys

Support to Government

AST has contributed to government policy and regulations, particularly through its transportation engineering and VPT programs, as well as supported government operations.

Contributing to regulations while supporting economic growth

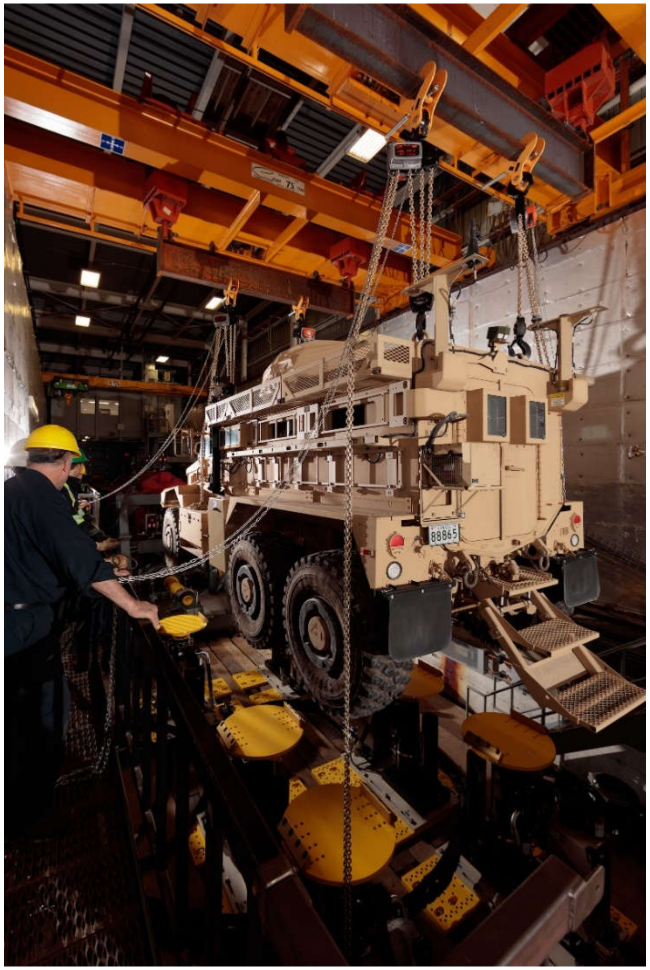
- contributed to hydrogen safety and measurements standards and codes with TC and Environment and Climate Change Canada (ECCC)
- developed heavy and light duty vehicle GHG emission criteria for North America with TC and ECCC
- developed heavy duty vehicles weights and dimensions regulations for harmonizing standards among provinces and territories in an effort to reduce trade barriers
- provided recommendations to TC on the effectiveness of automated train brake test technology
- supported TC in its involvement on an international working group developing standards and regulations for electric vehicles

Operational changes and cost savings

- for DND, improved the efficiency and preparedness of operational fleets, such as light armored vehicles (see picture)
- contributed to some cost savings and operational changes at ECCC and TC

Opportunity to regularly track and document policy influence

If AST tracked how it has impacted policy (e.g., changes to codes), it would be able to better understand and communicate how it supports federal priorities.



Pictured above: Vibration testing of armoured vehicle in AST's heavy structural dynamics lab research facility. The vehicle picture, the Cougar, is used to support the detection, investigation and disposal of buried improvised explosive devices.

Sources: Client survey, External interviews

Social Impacts

AST has contributed to a safe, secure and reliable transportation system, particularly for the benefit of transit-dependent and remote communities. It has created new opportunities in advanced manufacturing for students, and is positioned to support that sector more broadly with NGen.

Making it safer to travel Canada by road or rail

AST has contributed to social impacts, primarily through its transportation engineering and VPT programs. Overall, over two-fifths of AST's clients said their project had (16%) or would (27%) contribute to a safer, more secure and reliable transportation system in Canada. Socially impactful projects included:

- determining the cause of failed rail (e.g., projects with a Canadian regional railway)
- ensuring safety and increasing operational efficiency and longevity of public transit and passenger rail systems (e.g., projects for municipal rail operators in major Canadian cities), which supports populations more dependent on transit (e.g., older Canadians, persons with disabilities).
- supporting adaption to climate change / climatic conditions, particularly for Northern and remote communities (e.g., projects with VIA Rail/Infrastructure Canada on conditions in North)
- facilitating adoption of new trucking innovations (e.g., boat tails, rear impact guards) to improve vehicle safety for occupants and traffic participants, and to improve fleet efficiency.

Pictured above: AST staff and post-doctoral students from University of Ottawa working on fibre optic sensing for rail stress measurement.

New career opportunities in advanced manufacturing

AST has aligned the AMP with the Federal Government's Economic Strategy Table for the Advanced Manufacturing Sector; which itself seeks to address skilled labour shortages. Towards this, AST has hired more advanced manufacturing students from its university partners in Ontario and Quebec, tripling its student count from 4 to 15 in 2018-19 (as well as increasing transportation students from 1 to 4). AMP was also aligned with the NGen Supercluster. AST supported NGen's development (e.g., program design, project selection) and will work directly with some of its clients, actions which will support growth in this sector.

"AST stimulates the industry by offering high-profile job opportunities or internships in areas that are up-and-coming. It helps us to continue to grow and keep our workforce on this side of the border."

External interviewee

Sources: Client survey, Data review, Document review, External interviews

Environmental Impacts

AST's work in both material processing and manufacturing, and vehicle and transportation systems engineering has contributed to environmental benefits.

Half of AST clients working toward a cleaner environment

AST's activities in both its research areas are united by an overarching aim at generating environmental benefits. Half of AST's clients (51%) said their work with AST had contributed to a cleaner environment or was expected to do so in the future (16% has contributed; 35% in the future). In both of its research areas, many of AST's strategic research and technical service projects had 'green' goals such as reducing fuel consumption, developing eco-friendly products, and reducing environmental risks such as train derailments or nuclear waste leaks (see examples below). The PRC further suggested that AST explore opportunities for recycling non-biodegradable products within its material processing and manufacturing research.

Pictured above: Sample of isolation foam containing lignin, which was recycled from waste generated by pulp and paper mills.

Reduced fuel consumption and GHG emissions

- development of various electrification technologies (e.g., new tests to determine electric battery safety projects on electric motors for buses and automobiles, and work with hydrogen fuel cells)
- research on light-weight materials (e.g., plastic fuel tanks, new coatings for plastic windshields)
- aerodynamic testing and reduced wheel/rail interaction forces

Developed and promoted use of eco-friendly products

- research on alternative biomaterials recycled for use in automotive manufacturing, such as lignin from pulp and paper mills and carbon fibre from aircraft
- research on cleaner and recyclable composites including replacement of glass fibers used for light-weighting with urethane recyclability and composting of plastics
- promotion of eco-products (e.g., lead and radiation free products) to an OGD

Reduced other environmental risks and pollution

- work with TC on guidelines for long trains in reducing environmental impact/derailment risk
- work on rail system noise abatement to reduce noise pollution
- research for nuclear waste containers to reduce likelihood of contaminating surrounding ecosystems

Sources: Client survey, Document review, External interviews

CONSLUSIONS AND RECOMMENDATIONS •
AST RESEARCH CENTRE

Conclusion

Relevance

AST's competitive advantage is its inclusion of both materials processing and manufacturing and vehicle and transportation systems engineering within one centre, and its focus on multiple modalities. However, it has yet to fully leverage this advantage to it and Canada's mutual benefit as AST's two research sections operate largely independent of one another.

As is, AST, with its recognized expertise and large scale facilities, stands out as unique in Canada, though not internationally. Each section's research is aligned with the priorities of industry and of the federal government, but project selection has tended to be more reactive than strategic. AST has opportunities to respond to technological disruptions that intersect both the manufacturing and transportation sectors, to more directly contribute to Canada's prosperity, and to actively consider end-users.

Engagement

AST has room to grow its profile and engage more with Canadian industry and the research community. It has employed some successful engagement strategies, including its R&D group model for sectoral engagement, and participation in government and industry committees. Awareness and engagement have been relatively stronger for the materials/manufacturing section, compared to the transportation engineering section. Limited engagement by the latter section, particularly with key leaders in academia, will inhibit AST's entry into new and emerging areas. Greater engagement may raise AST's profile and lead to opportunities to leverage third-party funding and capabilities.

Scientific excellence

AST has advanced scientific and technical knowledge in material processing and manufacturing, and in niche areas of transportation engineering (e.g., rail) through technology deployment and optimization. It has the potential to lead in advanced ground transportation systems if it addresses the relevance, engagement, and resource issues described above.

Resources

AST has had sufficient resources to meet client needs to date, and has been building and transitioning its capabilities for R&D in new and emerging areas. However, it has been constrained by budget limitations and competing priorities (e.g., revenue targets), and some HR strategies have not panned out (e.g., retire-and-replace). As a result, AST lacks the critical mass of expertise and facilities needed to move into new and emerging areas. It will need to strategically make investments that contribute to its competitive advantage, and find more opportunities to leverage the capacities of third-parties.

Impact

AST's is contributing to economic, environmental, and social impacts, as well as government policy solutions. It has supported innovative businesses for growth as its industry clients have adopted new technologies, launched new products, and increased their competitiveness. AST is also creating new opportunities for Canadian researchers and businesses, particularly in advanced manufacturing, through its industrial R&D groups and the NGen Supercluster (e.g., new partnerships, increased innovation capacity). With OGDs, transit agencies, and other stakeholders, AST has contributed to a more safe, secure, and reliable transportation systems, particularly to the benefit of vulnerable populations. Overall, half of AST's clients are actively working towards a cleaner environment, including decreasing pollution and increasing the use of more eco-friendly products. Finally, AST has delivered evidence-based solutions to inform government decisions in priority areas such as transportation and defence.

Recommendations

Recommendation	Rationale
1. AST should articulate a plan that clarifies and promotes the integration of its capabilities in both material processing and manufacturing, and vehicle and transportation systems engineering, and pilot strategies to support this integration. This plan should identify where AST wants to be a leader (and commit resources accordingly), opportunities and risks for Canada posed by mutual disruptions to the advanced manufacturing and ground transportation sectors, and how it will contribute to Canada’s competitive advantage in these sectors.	AST has yet to fully exploit its breadth of research, namely its inclusion of both manufacturing and transportation domain capabilities within one centre. Moreover, it has tended to be reactive to client needs rather than proactively identifying and targeting issues of strategic importance to industry. AST has an opportunity to strengthen its position—and potentially that of Canada—if it were to leverage its other unique characteristics (i.e., recognized expertise, large scale facilities) and further integrate its capabilities.
2. AST should increase awareness among and engagement with key stakeholders in new and emerging fields. In particular, it should diversify and broaden its customer base in vehicle and transportation systems engineering, including greater collaboration with key players such as universities in order to access their competencies and facilities.	AST’s visibility among and engagement with stakeholders could be greater, particularly in the research community. It will need to engage with a broader range of clients and partners to effectively implement its proposed ATSP and enter new fields where it wishes to be a leader.
3. AST should identify and implement strategies to address talent and facility gaps, particularly for its work related to advanced transportation systems. In addition to operationalizing existing HR and facility strategies, AST should explore new strategies to increase capacity to ensure it successful entry into new fields.	While AST has had sufficient resources to meet client needs to date, it lacks the critical mass or expertise needed to move into new and emerging areas. Across sections, capital investments are needed to address emerging client needs and to position AST as a research leader. It is in a critical point as it is required to reduce its spending at the same time it intends to enter new areas. In order to enact their vision for the ATSP, it will need to set priorities and be strategic with its resources.
4. AST should determine and communicate strategic indicators that measure its contribution to the Canadian economy, demonstrate scientific excellence (using more industry-relevant metrics), and track influence on government operations, policy, and regulations.	The PRC found that AST has opportunities to better track its achievements and, in doing so, demonstrate leadership, and attract new business, partners, and talent. For instance, it demonstrated scientific excellence through technology deployment and optimization rather than scientific publications. Moreover, its contributions to economic, environmental, and social impacts, as well government policy solutions, were observed by the evaluation but have been insufficiently documented.

Management Response and Action Plan

Recommendation 1
AST should articulate a plan that clarifies and promotes the integration of its capabilities in both material processing and manufacturing, and vehicle and transportation systems engineering, and pilot strategies to support this integration. This plan should identify where AST wants to be a leader (and commit resources accordingly), opportunities and risks for Canada posed by mutual disruptions to the advanced manufacturing and ground transportation sectors, and how it will contribute to Canada's competitive advantage in these sectors. **Risk-level associated with not addressing recommendation: High**

Management Response	Measure of Achievements	Proposed Person(s) Responsible	Expected Date of Completion
Response: Accepted		Director General, AST	
Action 1: Establish a new internal strategic advisory committee and its governance to increase collaboration across the Automotive and Surface Transportation (AST) sites.	→ Strategic advisory committee and governance established by the release of Terms of Reference.		
Action 2: Define the value proposition of the Advanced Transportation Systems Program (ATSP).	→ ATSP plan approved by the Transportation and Manufacturing Division Vice-President.		September 2020
Action 3: Identify area of synergies in both material processing and manufacturing and vehicle and transportation systems engineering.	→ Project plans developed for two projects.		
Action 4: Revise AST strategic plan to better align with all four recommendations of the evaluation.	→ Revised version of the AST Strategic Plan approved by the Transportation and Manufacturing Division Vice-President.		June 2021

Management Response and Action Plan

Recommendation 2			
AST should increase awareness among and engagement with key stakeholders in new and emerging fields. In particular, it should diversify and broaden its customer base in vehicle and transportation systems engineering, including greater collaboration with key players such as universities in order to access their competencies and facilities. **Risk-level associated with not addressing recommendation: Medium**			
Management Response	**Measure of Achievements**	**Proposed Person(s) Responsible**	**Expected Date of Completion**
Response: Accepted **Action 1:** Revise stakeholder's engagement plan for the Advanced Manufacturing Program (AMP) and ATSP with an additional focus on vehicle and transportation systems engineering. **Action 2:** Develop a marketing plan to increase awareness of AST.	→ Stakeholder engagement plans for AMP and ATSP approved by AST Director General. → One new multi-partner project per program (including academia involvement) initiated. → Marketing plan developed and released. → A minimum of two major marketing initiatives completed as the rebranding of the Research Centre and/or sites, corresponding to 25% of the completion of the marketing plan.	Director General, AST	September 2021

Management Response and Action Plan

Recommendation 3			
AST should identify and implement strategies to address talent and facility gaps, particularly for its work related to advanced transportation systems. In addition to operationalizing existing HR and facility strategies, AST should explore new strategies to increase capacity to ensure it successful entry into new fields. **Risk-level associated with not addressing recommendation: High**			
Management Response	**Measure of Achievements**	**Proposed Person(s) Responsible**	**Expected Date of Completion**
Response: Accepted **Action 1:** Reassess critical expertise and facilities gaps related to AST.	→ Lester Road strategic plan with a specific section on competency requirements, gaps, and strategies developed and approved by DG and presented to Transportation and Manufacturing Vice-President.	Director General, AST	June 2021
Action 2: Explore options to increase investment for talent and facility gaps in AST, internally and externally.	→ Identified and documented ways to acquire additional talent and capital investments.		

Management Response and Action Plan

Recommendation 4			
AST should determine and communicate strategic indicators that measure its contribution to the Canadian economy, demonstrate scientific excellence (using more industry-relevant metrics), and track influence on government operations, policy, and regulations. **Risk-level associated with not addressing recommendation: Low**			
Management Response	**Measure of Achievements**	**Proposed Person(s) Responsible**	**Expected Date of Completion**
Response: Accepted. **Action 1:** Develop an AST Performance Framework in collaboration with Policy, Strategy and Performance (PSP) Branch including a Management Toolkit. **Action 2:** Develop a post-project consultation to collect quantitative metrics and qualitative evidences on the impact of AST's work on the on clients/collaborators, government policy solutions, and / or scientific excellence. **Action 3:** Develop a tracking tool for participation in committee and conferences to track influence.	→ AST Performance framework completed and approved by AST management committee. → Strategic indicators monitored at established frequency. → Post-projects consultation developed and implemented. → Documented participation in committee and conferences.	Director General, AST	June 2021

APPENDICES • AST RESEARCH CENTRE

Appendix A: Methodology

Bibliometric Study

NRC's Library and Information Management Services conducted a bibliometric analysis of peer-reviewed publications affiliated with the research centre and indexed in Scopus for the period 2013-2018. This analysis was used to assess the research centre's impact, as well as to benchmark it against NRC, Canada and the world. The list of publications and patents was developed in consultation with AST.

Key Informant Interviews

Interviews were conducted with 52 stakeholders (31 internal and 21 external) to collect information such as personal experiences, opinions and expert knowledge related to the relevance and performance of AST. This includes interviews with clients (n=15) to compliment the client survey as well as external stakeholders such as industry associates (n=6), split proportionally between AST's materials/manufacturing and transportation engineering sections. This information was used to complement other lines of evidence and to contextualize quantitative information.

Client Survey

A web-based survey of AST's clients was conducted to assess AST's relevance, engagement, resources and impact. A total of 128 clients responded, including 80 that worked with the materials/manufacturing section, 39 for transportation engineering, and 9 that worked with both; rates proportionate to AST's total client population. An external consultant conducted follow-up calls to increase the response rate, which was 28%, a rate in line with industry standards.

Document and Literature Review

Internal and external documents were reviewed to provide context and to complement other lines of evidence in assessing relevance and performance. Internal documents included program business plans, RC operational and strategic plans, and presentations. External documents included industry studies, market assessments, and documents related to government priorities.

Data Review

Research centre and program administrative and performance data for 2013-14 to 2018-19 were reviewed to provide information on program inputs (i.e., resources), outputs, and client reach. This included financial data, human resource data, project data and intellectual property data.

Peer Review

A peer review committee (PRC) was convened to assess AST along five dimensions (relevance, engagement, resources, scientific excellence, and impact), and identify ways AST can integrate two research sections. The PRC included eight members plus one chair, and balanced individuals with expertise related to materials processing and manufacturing, and vehicle and transportation systems engineering. They included national and international representatives from academia and industry. To ensure objectivity and avoid conflicts of interest, peer review committee members signed a confidentiality and conflict of interest agreements. The process included:

1. Reviewing background material produced by AST and by the NRC evaluation team.
2. Participating in a pre-site visit teleconference to discuss their initial assessment of the RC, information gaps and questions.
3. Participating in a two-day site visit to the NRC.*
4. Writing a peer review report.

*The chair and members with transportation engineering expertise also participated in a one-day visit to NRC-Ottawa for the concurrent facility review (see next page).

Appendix A: Methodology

Comparing AST by Research Area

AST's research covers a variety of areas, from material processing and manufacturing (applied to the automotive sector), to vehicle and transportation systems engineering (including rail, heavy duty vehicles, and defence fleets). As a result, data were analyzed according to, and findings are reported by, these two broad areas. This was done to compare particularities or nuances in the work of AST relative to their objectives, rather than to rank each section of AST's relative performance. A comparison of performance would be flawed as there are differences in the work AST conducts in materials/manufacturing and transportation engineering. To conduct these analyses, data was split when possible at the per project level (e.g., revenues and expenses, program outputs). In some cases however, data splits were not as precise and proxies were employed (e.g., HR analyses were based on locations, each of which mostly aligns with one research area over another).

Ongoing Facility Review

In addition to this evaluation, AST has received, and will receive additional recommendations and advice regarding its facilities, namely through the NRC-wide facilities review process. Transportation engineering facilities were reviewed concurrent to this evaluation, but materials/manufacturing facility reviews are still ongoing. Where possible, evidence from the facility review was incorporated into the evaluation's lines of evidence. Self-assessments completed by TEC management were included in the document review, and, as mentioned above, some peer reviewers participated in an additional day of site visits and discussions in Ottawa, giving them extra insights into AST's operations.

Appendix A: Methodology

Limitations and Mitigation Strategies

Challenges associated with PRC

To provide an objective, independent assessment of the RC, arms-length experts were sought to participate in the peer review process. Given the need to be independent and objective, experts selected for PRC may not have in-depth knowledge of the RC and its activities, or the NRC. Additionally, each member comes to the exercise with their own experience, expertise and associated biases.

In order to ensure the needed expertise on the committee, and to select the best possible committee composition, the project team consulted with the RC's senior management and advisory board, and with the Knowledge, Information and Technology Services branch, to identify and invite the peer review chair and members. All PRC members were vetted and approved by the research centre VP and DG.

To mitigate any bias throughout the peer review process, the evaluation team tries to ensure the inclusion of experts from various areas of expertise, including different genders, geographic locations, and representatives from various types of organizations. In addition, at least one Canadian representative is sought in order to bring an understanding of the Canadian context.

Data and document availability

AST did not systematically track its outreach activities, such as conference or trade show attendance. To mitigate this gap in data, interviews with internal staff were used to gather examples. In addition, AST did not systematically track professional development of its staff. Instead, time spent on internal R&D projects was used as a proxy for competency development.

Use of publications to measure excellence

The challenge with bibliometric analysis is that there is a time lag of citation of published work. As a result, the actual use of more recent publications is likely underestimated in the current study. To mitigate this limitation, other lines of evidence were used to assess the excellence and scientific impact of AST's research, including the use of an expert peer review.

Appendix A: Methodology

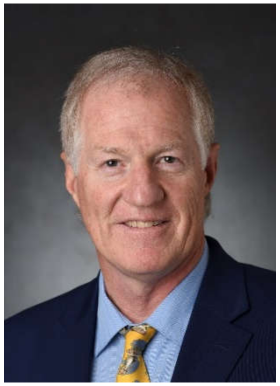
PRC Members – Expertise in Material Processing and Manufacturing

Abhay (Abe) Vadhavkar, Chair

Recently Retired Director, Materials and Manufacturing Technology – Centre for Automotive Research

Thomas Kelly

Executive Director and CEO – Automation Valley



Tim Eden

Head of the Materials Processing Division, the Applied Research Laboratory and Professor – Pennsylvania State University

Maria Auad

Director, the Centre for Polymers and Advanced Composites and Professor, Centre for Bioenergy and Bioproducts, Engineering Group – Auburn University

Appendix A: Methodology

PRC Members – Expertise in Vehicle and Transportation Systems Engineering

Yuping He

Professor – University of Ontario Institute of Technology

Donald Eadie

President – Don Eadie Consulting

Ahmed Shabana

UIC Distinguished Professor and Richard and Loan Hill Professor of Engineering – University of Illinois at Chicago

Séamus Parker

Principal Researcher, Transportation – FPInnovations

Marianne Hatzopoulou

Associate Professor, Canada Research Chair – University of Toronto Transportation Research Institute

Appendix B: AST Logic Model

AST Logic Model, 2019/2020

Ultimate Outcomes (10+ years)

Economic Impacts:

- Canada's global position is strengthened within the transportation and manufacturing industries (e.g., increased competitiveness of Canadian firms attracts international investment, and increases exports and thus increases GDP; increased global ranking of Canada's top companies; increased prominence of Canadian R&TD clusters within global supply chains)

Environmental Impacts

- A cleaner and healthier environment (e.g., reduce fuel consumption and GHG emissions; more zero emission vehicles on Canadian Roads; reduced environmental impacts from derailments; more use of eco-products in transportation and other selected industries; and, increase the use of sustainable biomaterials in manufacturing)

Social Impacts:

- A safer, more secure, more efficient, and more reliable Canadian transportation system (e.g., improved safety of vehicles, occupants and traffic participants; increased operational efficiency and safety of rail system; reduced cycle time for goods transportation; and, improved individual mobility)
- New, better career opportunities available to Canadians in advanced manufacturing (e.g., higher-value jobs; more inclusion of traditionally under-used talent pools, such as Indigenous Peoples, Canadians with disabilities, and women)

Intermediate Outcomes (6-10 years)

Business Innovation:

- Improved innovation capabilities for Canadian firms, Government agencies & academia
- Creation & growth of Canadian firms, including increased revenues, jobs creation & productivity, due to:
  - Emerging and innovative technologies adapted in SMEs (e.g., light weighting)
  - Improved manufacturing productivity and competitiveness (e.g., reduced product time to market)
- Canadian transportation and advanced manufacturing ecosystems developed and matured
  - Objectives of NGen Supercluster members and industrial R&D groups furthered
  - Integrated value chains and strengthened supply chains
- Canadian firms supported to reduce their environmental footprint within the manufacturing supply chain

Advancement of Knowledge

- NRC is recognized internationally for its world-class R&TD in ground transportation and advanced manufacturing
- NRC is recognized as the partner of choice in manufacturing process research, innovation, and know-how.

Government Policy Solutions

- World-class mobility technology brought to DND and Canadian Armed Forces (e.g., increased operational efficiency and preparedness of defense fleets).
- Transport Canada supported in developing science-based regulations and policies to enhance the safety of the Canadian transportation system.
- Federal priorities for the advanced manufacturing sector supported (e.g., apprenticeships and experiential learning to address skilled labour shortages; inclusion of traditionally under-used talent pools)

Immediate Outcomes (1-5 years)

Business Innovation

- Transferred knowledge & technical skills for capacity development
- Transferred technology (to multiple players on the supply chain) to rise digital maturity of Canadian industries and better position them in the global ecosystem
- Creation/expansion of novel value chain
- NGen Supercluster supported

Advancement of Knowledge

- NRC is recognized as a national leader for AST research & technical excellence
- Unique intellectual assets generated by NRC research leaders
- Heightened awareness of NRC's value added offerings in ground transportation systems and advanced manufacturing

Government Policy Solutions

- Science & technologies support government regulations (e.g., environmental, social)
- Alignment with global NRC Defence Strategy and partnership with DND
- Alignment of advanced manufacturing strategy with federal priorities for the sector (e.g., attract global mandates, grow firms to scale, speed up technology adoption, and equip workers for jobs of tomorrow)
- Knowledge and technologies transferred to federal, provincial, and municipal OGDs to better position them to implement mobility systems of the future

Outputs: People Development, Infrastructure, Firms Supported, Scientific Achievements, and Collaborations.

Activities: Facilitate Scientific, Technical & Organizational Capacity; Build Scientific & Technical Capacity; and, Deploy Scientific & Technical Capacity

Inputs: NRC Investment, Earned Revenues, Contributions from other NRC Research Centres & Collaborators/Partners, NRC Common Services & SSC, HQP, and Facilities.